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E. FALKNER HILL T. CECIL GRAY

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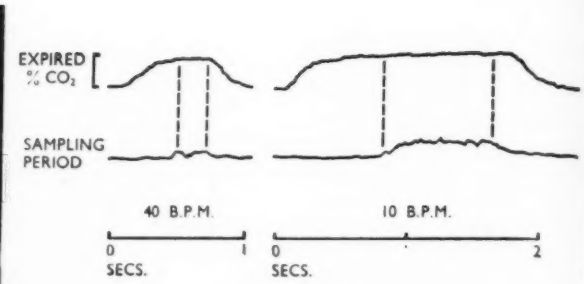

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BRITISH JOURNAL OF ANAESTHESIA

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EDITORIAL

THE cause of emphysema is not known, although medical literature abounds with articles which discuss it. In contrast, the profound changes in lung function that it can produce are well recognized, yet those who have written about it in relation to anaesthesia are very few in number.

In this issue of the Journal an attempt has been made to summarize the anatomical and functional damage to the lungs of this disorder in relation to the clinical picture, so as to provide a background for the anaesthetist which should help both in the recognition of the condition, and in dealing with some of the practical problems in anaesthesia it produces.

Anaesthetists find that the disorder, when well established, is often a source of great difficulty; minor degrees of it offer little disturbance. Thus the contributors to the symposium have considered the effects of emphysema when these are well marked.

Altered pulmonary function holds the key to a better understanding of the problems involved in the treatment of patients with emphysema; it may well be that anaesthetic difficulties are directly related to a decrease in one or more of the lung functions; some of these can be measured with simple apparatus. Since the anaesthetist often has to effect profound alteration of respiratory function in order to ensure good operating conditions for surgeons, particularly during upper abdominal operations, it is highly desirable that facilities for the assessment of lung function should be provided for anaesthetists and others in all general hospitals.

Hypoventilation in emphysema which may lead to carbon dioxide narcosis is of considerable importance. Recently an attempt has been made to treat some of these patients by a regime with tracheotomy followed by intermittent positive pressure respiration. An anaesthetist might therefore be approached by a physician with a request that he should undertake the care of such a patient. Treatment is likely to be needed for several days and is associated with problems of great complexity; it is not known which types of patient with emphysema or how many of them, would benefit. It would therefore be unreasonable to expect any specialist to cope with this situation alone.

There is every justification for the formation of special teams composed of anaesthetists, physicians, neurologists, surgeons, physiotherapists and nurses, and they should be suitably equipped to deal with patients with respiratory difficulties from various types of disorder.

Each unit needs direction, and to designate such a team as an emphysema or tetanus unit invites difficulties; the phrase "respiratory unit" seems more appropriate. A consultant in any branch of medicine, unless he has had special training, would not normally be capable of dealing with the day-to-day issues raised by the problems of treatment set by respiratory failure. Those who have turned practical experience to advantage in the care of unconscious patients over prolonged periods would seem particularly fitted to grapple with the responsibilities of this work.

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PATHOLOGICAL ASPECTS OF EMPHYSEMA

BY

LYNNE REID

Institute of Diseases of the Chest, Brompton, London

IN this country emphysema is usually associated with chronic bronchitis; in dealing, therefore, with emphysema the anaesthetist is concerned not only with disturbed respiratory function, but also with the production of sputum which is characteristic of chronic bronchitis and persists even with the control of the recurrent infections to which patients with that disease are prone. The changes in the lung periphery in chronic bronchitis include not only emphysema but also such damage as fibrosis and obliterative bronchiolitis; these last two are important for their contribution to dyspnoea and for their effect on the pattern of disturbed function characteristic of emphysema.

Normal Anatomy.

The bronchial tree branches repeatedly and narrows progressively from the trachea to the respiratory part of the lung, and its structure varies at different levels, altering its behaviour in disease. Bronchial pathways to alveoli near the hilum (known as "lateral") are shorter than those (the "axial") which pass to a distal surface of a segment. The number of their branches varies, axial pathways having usually a maximum of twenty-two to twenty-five before reaching a terminal bronchiole, the lateral having considerably fewer. The shortest pathways, supplying lung close to the hilum, may have as few as eight, and a pathway branches more frequently towards its extremity, five or more branches arising within its last centimetre. These are either bronchioles or, if cartilage is present, bronchi. The most peripheral air tube is the terminal bronchiole, the word "peripheral" being used here to describe bronchial structures which are peripheral in the pattern of branching, rather than subpleural.

Bronchi are air tubes proximal to the point where cartilage disappears, bronchioles lying distal to it. Practically the whole circumference of the more proximal or larger bronchi is supported by plates of cartilage, while in the more peripheral there is only an occasional plate, usually at points of branching. The behaviour of the bronchi in collapse depends partly on the amount of cartilage in their walls, since the proximal ones may, by reason of their inherent rigidity, remain patent, while the peripheral bronchi behave like the bronchioles and alveoli, their walls collapsing into apposition (Hayward and Reid, 1952).

The distribution along an axial pathway is of the order of five large and ten small bronchi and five bronchioles, the last of these being the terminal bronchiole. Beyond lie the respiratory bronchioles which have alveoli opening into their lumen and it is, therefore, not unreasonable to include them in the respiratory part of the lung. The acinus, as described by Rindfleisch (1873), is a useful respiratory unit, being the lung supplied by a terminal bronchiole.

The secondary lobule has been described as the unit completely enclosed by connective tissue septa (Miller, 1947), but this is an unsatisfactory definition, for septa are not present throughout the lung and even in the subpleural region they are not complete (Reid and Rubino, 1958). The secondary lobule has been redefined (Reid, 1958) as that group of three to five bronchioles, arising at intervals of about 2 mm, and the volume of lung they supply of approximately one or two cubic centimetres.

The Secretion of Mucus in the Bronchial Tree.

The bronchi are the chief site of mucus production as well as the pathways which conduct air to the peripheral respiratory part of the lung. Passing from the hilum of a segment to its most

distal pleural surface, a bronchial pathway may branch more than twenty times before reaching the level of the terminal bronchiole. Cartilage and mucous glands are usually found together. In the proximal five of the twenty branches a relatively large amount of cartilage and numerous mucous glands are present, over the next ten branches both these structures are relatively infrequent, and over the last five there is no cartilage, so that, by definition, these air tubes are bronchioles, and in these there are no mucous glands. The surface epithelium includes goblet cells, which also secrete mucus, and these, although numerous in the proximal bronchi, decrease progressively towards the periphery. It will be seen, therefore, that mucus is secreted mainly in bronchi, particularly the larger ones, while in the peripheral part of the lung secretion is minimal.

In spite of its importance, many fundamental aspects of mucus secretion, including the factors controlling its amount and physico-chemical nature, are not yet understood. The normal bronchial tree produces approximately 100 ml of secretion in a day without giving rise to sputum, but what increase must occur before any of it is coughed up as sputum is not known, nor, although the patient may cough up several hundred ml of sputum in a day, is it known what part of total secretion this represents. Removal of mucus secreted in the lung depends, in part, on the normal functioning of the "ciliary escalator". Although the ciliary layer may be destroyed in acute infection, with healing of the epithelium it reforms, but it may still be insufficient to cope with the excessive discharge from goblet cells and glands. The activity of cilia may be reduced by a lowering of temperature, an alteration in humidity, or the introduction of noxious agents (Dalhamn, 1956).

Changes in the Bronchioles and Alveoli—within the Secondary Lobule.

Although the name chronic bronchitis points to changes in the bronchi, it is in the peripheral part of the lung that the damage (including emphysema) occurs which is of the greatest functional significance. No lesion is specific of chronic bronchitis; the disease is characterized rather by the patchy distribution of small foci of damage which is the result either of infection or obstruction in peripheral airways (Reid, 1957). The relative importance of these two is often difficult to establish, as one predisposes to the other, and infection may cause its serious damage primarily through obstruction. In the bronchioles evidence of increased mucus secretion may be seen in the increased number of goblet cells giving a positive stain for mucus; in addition, purulent bronchiolitis and calibre change, both of dilatation and stenosis even to the extent of obliteration, may be present. In the alveoli pneumonic consolidation, oedema and collapse may all be evident. These changes in bronchioles and alveoli are usually associated, but the degree of change in the latter does not always seem to be as severe as might be expected from the type and degree of bronchiolar damage.

This discrepancy in the degree of damage probably results from collateral ventilation—a phenomenon frequently demonstrated by the anaesthetist during pulmonary resections and one which is relevant in the interpretation of the morbid anatomy of the lung. Van Allen et al. (1931) have shown that when the human segmental bronchus is obstructed collapse does not necessarily ensue, owing to collateral air drift across alveolar walls and therefore between segment and segment. Furthermore, if air is introduced under pressure into one segmental bronchus which is otherwise blocked it will, as a result of this phenomenon, escape from adjacent segmental bronchi without overdistension of any segment. Van Allen et al. (1931) first described this drift of air across alveolar walls and it has since been confirmed in studies on living human subjects at bronchoscopy (Baarsma and Dirken, 1948). A normal alveolar wall permits air drift, but if rupture occurs, as in certain types of emphysema, drift develops into direct continuity between lobule and lobule—direct lateral communication rather than collateral ventilation probably describes the phenomenon more accurately.

In many patients with chronic bronchitis there is clinical evidence of infection and sputum may become purulent or increase in purulence. Progressive damage due to this infection may be held responsible for increasing shortness of breath in some patients, but in others the same reduction in respiratory reserve may occur without such clear-cut association. In these cases simple obstruction

by mucus or foci of pulmonary infection too small to give overt sign, may be the cause of permanent damage.

Some of the changes listed are acute and will resolve, others are chronic and even if, in part, they disappear, a residue of permanent damage remains which is, mainly, of two types, (1) scarring or fibrosis, and (2) destruction of alveoli; this is one type of emphysema (figs. 2 and 3). In some patients with chronic bronchitis small scars in the lung are numerous, although their distribution is usually irregular and uneven. These scars are more frequent in the subpleural region and represent one form of damage which contributes to reduction in pulmonary reserve. Into such nodules a considerable volume of normal lung may be condensed. As the resting total lung volume of these subjects is often greater than normal, the presence of the scars points to some distension in the remaining lung.

The other type of permanent damage is that associated with ulceration or destruction of respiratory tissue (fig. 1). Acute inflammatory changes may destroy part of the network of the alveolar walls so that even if pus is coughed up or absorbed the structural damage remains. Such micro-abscesses, although they may occur more proximally in the bronchial tree, are found particularly in the most minute bronchioles, the terminal and respiratory bronchioles—in what may be called the region of the bronchiolo-alveolar junction. A form of emphysema is the inevitable consequence of such destruction of tissue.

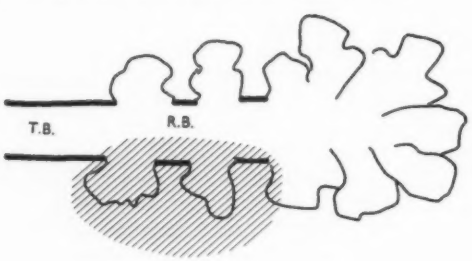

FIG. 1

Showing a terminal bronchiole, respiratory bronchiole (i.e., one with alveoli opening into its lumen) and distal alveoli. There may be three generations of respiratory bronchioles. With infection, part of the lung (shaded) may be destroyed, giving rise to emphysema, as shown in figure 2.

Emphysema.

In the range of techniques which are used to diagnose emphysema lies one source of confusion, that they measure different aspects of the changes in the lungs or are sensitive to them in varying degree. For example, the pathologist, using microscopic methods, may diagnose emphysema in a single section, in itself insufficient to cause symptoms or to be detectable by the physiologist, who measures variation in total function. The radiologist is in an intermediate position. He may detect severe local change in a subject whose respiratory function is within normal limits, or, even if the pathological changes do not give rise to localized hypertranslucency in a radiograph (figs. 4 and 5), he may be able to diagnose emphysema by secondary changes on the diaphragm, heart and vessels.

The anaesthetist is concerned with emphysema mainly as a functional disturbance and he is therefore worried more by the destruction type in which there is some loss of tissue than by the distension type which is milder in its effect on function (Reid, 1958). In distension emphysema, the alveoli may be enlarged although they are structurally intact. In several cases observed by the author at operation, while the anaesthetist found the lung easy to inflate, it was slow to deflate. This contrasts with graver degrees of emphysema, of destruction type, in which the anaesthetist finds it difficult to inflate the lung, deflation again being slow.

The term "emphysema" as a pathological description is applied to a range of appearances, from the small collection of air less than a centimetre in diameter and surrounded by normal lung, to bullae of various sizes and shapes, which may occur in a lobe in which no normal respiratory tissue remains (fig. 6). But the clinical picture results from the total damage of all lesions throughout both lungs and is also influenced by the different types of damage and their distribution.

Small Focus of Emphysema.

The most important single feature in the development of emphysema is the destruction of lung, particularly the alveoli, and infection is a main cause. Certain results of destruction, of even a small volume of lung, are serious and are illustrated in figure 2. With the loss of anatomical integrity there may be an increase in volume of

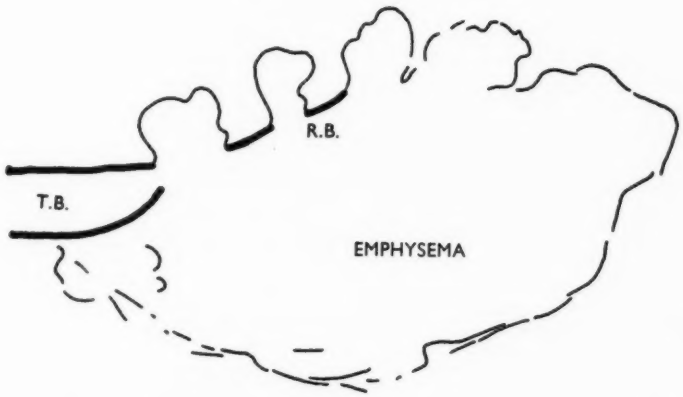

FIG. 2

With destruction the bronchiolar wall may float free, resembling a flap valve. The acinus (respiratory tissue distal to a terminal bronchiole) may increase in volume.

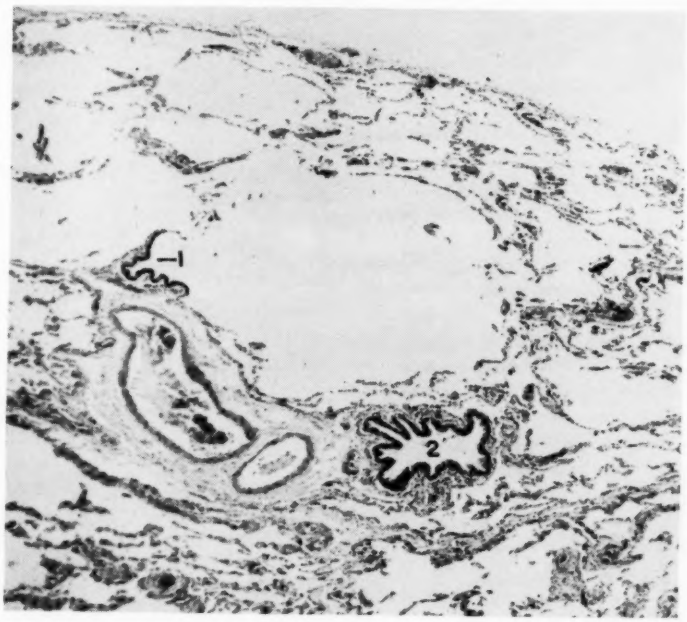

FIG. 3

Section including pleura and an adjacent focus of emphysema: (1) a bronchiole whose alveolar communications are destroyed; (2) a larger bronchiole whose wall is no longer cushioned on all sides by intact normal lung.

the part affected, destruction of capillary bed and perhaps impairment of supply to the distal part of the respiratory unit. The wall of the bronchiole is no longer held in position by the delicate but elastic system of guys furnished by intact normal lung, and its structure comes to resemble that of a flap-valve (fig. 2). The focus of emphysema illustrated here is intra-acinar in that it lies within the respiratory tissue distal to a terminal bronchiole.

Development of Bullae.

Several factors may contribute to the development of larger lesions and their operation is probably complex. Initial ulceration may involve not simply the few alveoli within one acinus, as in the illustration; the amount of ulceration or destruction may be so widespread that coalescence results and a large volume of lung is replaced by air. A secondary effect is the interruption of blood flow, which, although serious, cannot be assessed accurately. Destruction is the major form of damage, but distension also contributes, being probably particularly important in the subpleural region, where the presence of connective tissue sepa tends to produce bullae as the result of distension of subpleural foci of emphysema above the surface. Figure 6 represents the arrangement seen in many of these bullae, the connective tissue septa and pleura largely determining the final appearance of the lung.

When the loss of alveoli has proceeded to this degree the cut surface of the lung consists of tenuous strands and ragged shreds. Microscopic examination shows that the former represent blood vessels and bronchi with their connective tissue sheaths, as well as tags of alveolar remnants. With the loss of the alveolar structures the incomplete nature of the septa and their fenestrations become apparent and the free continuity between neighbouring parts of the lung is striking. A similar amount of destruction as represented by such bullae is seen also in the deeper part of the lung.

The final size of a bulla is no indication of the amount of normal lung it represents. Lung between neighbouring connective tissue septa, representing perhaps only a few secondary lobules or a few cubic centimetres of normal lung, may distend to the size of a grapefruit, or, on the other hand, a lobe may be little increased in total volume and yet so emphysematous that it is represented only by shreds of tissue.

Distribution of these Changes in the Lung.

So far we have been concerned with individual lesions, but it is the total effect of a multiplicity of them that is important in the development of respiratory symptoms and the production of a disturbed pattern of respiration.

These changes may not be present throughout the lungs or if present they may not be uniform; they may vary to such an extent that adequate description is a matter of considerable difficulty. The term "generalized emphysema" is usually taken to mean that the whole lung is affected; at the same time, it is used to indicate that the whole of a lobule is involved, in contrast to the type of emphysema described as centrilobular because it appears confined to the centre of the lobule (Leopold and Gough, 1957). "Bullous emphysema" is often used when bullae are present, but again it may be localized or generalized. The latter condition is sometimes called diffuse, but this has the disadvantage that it suggests a uniformity which is not appropriate to a focal type of lesion. "Focal", again, has been applied to localized lesions of emphysema (Maclean, 1957), but is also used to designate emphysema in association with scars.

Changes in the Blood Vessels.

The later stages of emphysema may be characterized by the features of cor pulmonale (Stuart-Harris and Hanley, 1957). Ulceration occurring in emphysema, and fibrosis and scarring frequently found in lungs showing the changes of chronic bronchitis, all lead to a loss of the capillary bed. This is probably the most fundamental change in the blood vessels, and in the later stages may be associated with an increase in the flow of blood through precapillary anastomoses between the bronchial and pulmonary arterial and venous systems, a more complex disturbance which is not yet understood (Cockett and Vass, 1951; Tobin, 1952; Liebow, 1953).

Correlation between Radiography (including Bronchography) and Pathology.

Accurate correlation of clinical and radiological features with the pathological lesion or, rather, the aggregation of pathological lesions, is not always

possible; but certain conclusions of a negative nature can be drawn. The presence of bullae is of itself no indication of the total severity of emphysema. If the rest of the lung of a patient suffering from dyspnoea is normal, excision of localized bullae seen on a radiograph may result in a marked improvement in the patient's condition. On the other hand, a patient may be short of breath, although no bullae are visible on the radiograph. All too often, however, while it may be in only one or two regions that the nature and distribution of the changes give the appearance of bullae, the disease has, nevertheless, damaged all lobes.

Hypertranslucency, one of the radiographic signs of emphysema, results from an increase in air and reduction in blood in the respiratory tissue relative to surrounding lung. The linear shadows associated with hypertranslucency enable the diagnosis of "bulla" to be made, where otherwise one might diagnose a "bullous area" (Simon, 1956). While the respiratory part of the lung may reveal no abnormality the damage caused by emphysema may be widespread and severe enough to affect the diaphragm, blood vessels, hilum and heart. Because of their functional implications these secondary effects are of even graver significance than localized hypertranslucency.

Bronchography, when available, is useful in

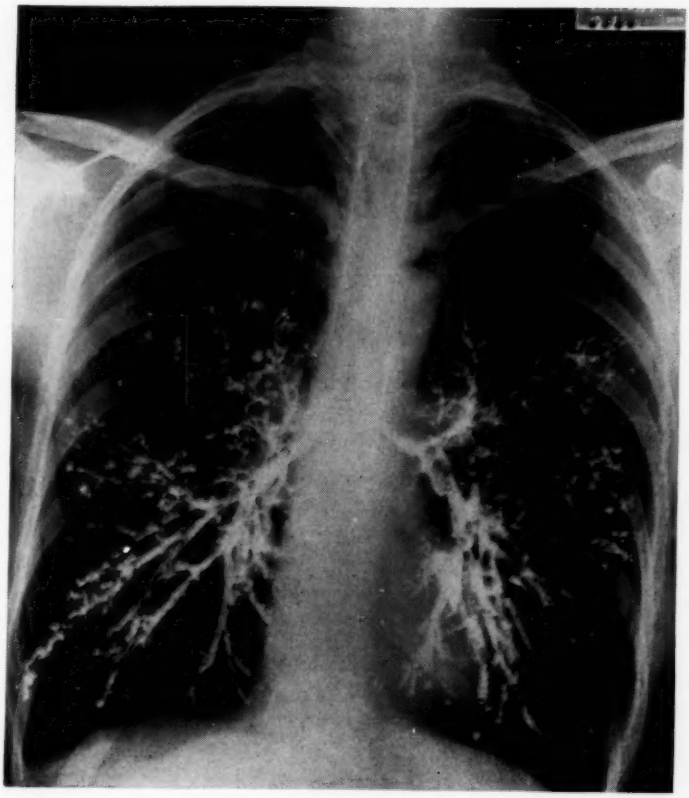

FIG. 4

Bronchogram in a patient whose plain radiograph showed hypertranslucency at the base of both lungs, demonstrating that the axial bronchial pathways pass into the area, suggesting that here the whole lower lobe is involved in this change.

localizing the damage in the lung, pointing to the site of the impaired function. Briefly, in emphysema the changes are of two kinds: (1) deficiency of peripheral filling resulting from impairment of entry of radio-opaque material into an emphysematous region, and (2) poor ventilation giving rise to poor "suck" of contrast medium. The abnormal shadows arising from the variety of bronchial or bronchiolar distortion associated with chronic bronchitis may produce irregular tapering ends to the filled bronchial pathways or pools of radio-opaque material representing bronchiolectasis (fig. 5) (Simon and Galbraith, 1953).

Relation of the Pathological Changes to the Altered Pattern of Respiratory Function.

The different types of lesion which have been described will in summation determine the degree of pulmonary impairment, and the particular combination of these lesions in different patients will influence the details and pattern of disturbance. Detailed correlation between lesion and function is, therefore, not possible.

One general disturbance of obvious importance to the anaesthetist is the reduction in elasticity of the lungs. This used to be given prominence as a function of elastic fibres, but the property of elasticity does not reside in any one type of tissue. Probably the most important single factor in the normal volume changes which take place with the balance play of respiratory forces is the anatomical integrity of the meshwork of the lung; the significant individual lesion in emphysema associated with chronic bronchitis is loss of anatomical integrity at the bronchiolo-alveolar junction, transforming it into the structure of a flap-valve (fig. 2). Such a lesion multiplied many times and perhaps associated with larger collections of air in bullae gives the final picture of trapping of air, a characteristic feature of empyhysema demonstrated by the pathologist when he squeezes an emphysematous lung, shifting gas from one part to another without succeeding in deflating it.

Bronchial Obstruction and Ventilation.

Impairment of ventilation is one of the important changes in emphysema. Several factors may contribute to obstruction of airflow in the bronchi, some amenable to treatment, others not. Bronchospasm, obstruction of the bronchial lumen by mucus, oedema and congestion of the mucosa, the valve-like action of bronchial and bronchiolar walls, all play their part, and the trapping of air or the failure of the lungs to empty on expiration is in itself an obstruction to further air entry. This is the vicious circle in emphysema, one which the anaesthetist may accentuate by artificial respiration. Wheezing which does not clear with bronchodilators may be heard in emphysema and may result from some of these causes or possibly when emphysematous lung breathes into itself, air shifting from one part of the lung to another.

The other important functional change in emphysema is the unevenness, as between themselves, of the air and blood supply to a given part of lung. The degree of impairment in ventilatory and in perfusion tests may be unequal, since the degree of destruction of the capillary bed does not necessarily vary directly with the degree or type of bronchiolar damage.

Operation for Excision of Localized Emphysema.

Operation is sometimes undertaken to remove localized volumes of emphysematous lung which, because of their size, are thought to be unduly compressing the rest of the lung. The operation findings in such cases vary considerably, but two extreme examples will illustrate something of the range of changes. A bulla or system of bullae may virtually be cut off from neighbouring lung, so that although it may be of considerable size and compressive effect, it may not be detected by preoperative respiratory function studies. On the other hand, a bulla may be in free communication with the underlying lung, so that when its roof is removed large openings are seen in its base. These often resemble bronchial openings, but they are usually communications with alveolar tissue of neighbouring lobules. A paradoxical type of respiration may result as, on expiration, air is forced into the bulla from deeper lobules in the lung. In most cases which come to operation there is relatively free communication between the lung substance and the bulla; the anaesthetist is made only too conscious of this by the loss of his anaesthetic mixture when the bulla is opened.

Distension of Lung after Resection.

After excision, the remaining lung tissue distends in varying degree, tending to fill the thoracic cage. The effect of prolonged overdisten-

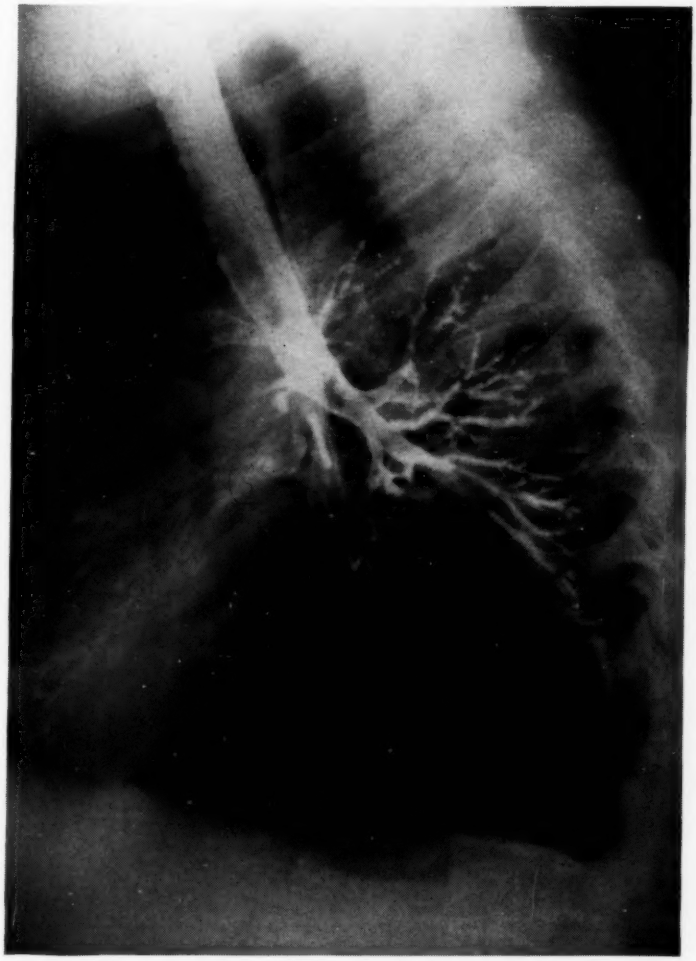

FIG. 5

Lateral bronchogram in patient with hypertranslucency at left base showing displacement and compression of bronchial pathways—an antero-posterior film showed some pathways displaced toward the mediastinum. The absence of bronchi in hypertranslucent area suggests that only a subsegment at the most is represented.

FIG. 6

The cut surface of a lobe showing small foci of emphysema (centrilobular in type) at the right and a system of intercommunicating bullae to the left, which was even more distended in life and was visible on a radiograph.

sion of normal lung is not known, nor whether in time it may of itself cause disruption; but recent studies suggest that it does not necessarily produce the functional disturbance of emphysema (McIlroy and Bates, 1956). Where the residual lung is already affected by chronic bronchitis or emphysema the result of resection cannot be foretold with certainty; and while expansion of the relatively normal parts of the lung may even promote efficiency of function, it is more likely that, by causing further overdistension of emphysematous regions, the loss of respiratory function may be accentuated.

In anaesthetizing the patient suffering from emphysema one of the main practical problems is assisting expiration—in which negative pressure is sometimes used. In trying to deflate an emphysematous lung the pathologist finds that sudden manual compression may cause no expulsion of air where gentle pressure might succeed. The anaesthetist handling the living lung, indirectly through an anaesthetic machine, may have similar experience. The response of different lungs to negative pressure varies considerably, but if the method is to be successful it is probably desirable that it be applied gently and critically in the light of the lung's response.

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THE FUNCTIONAL PATHOLOGY OF EMPHYSEMA

BY

P. HUGH-JONES

Postgraduate Medical School of London, Hammersmith Hospital, W.12

EMPHYSEMA produces more widespread disturbances of lung function than any other disease. Thus, it is of particular importance to the anaesthetist.

Modern techniques of respiratory physiology have only been applied in clinical medicine during the last decade or so; but, in this short time, they have increased our knowledge of the disturbances in lung function enormously. The anaesthetist need not know details of the physiological techniques themselves or of the lung function tests used, but it is becoming increasingly obvious that an understanding of the functional changes in the lungs, and hence of the significance of function test results, is essential if anaesthetics are to be given safely to patients with emphysema. The subject is, however, so large that only a brief review is possible in this symposium.

Appreciation of the functional changes in emphysema will help the anaesthetist to recognize and assess emphysematous patients before operation, deal with complications which arise during and after anaesthesia, help him decide when it is advisable to postpone operation (and the benefit to the patient that can be expected if this is done), or to decide when anaesthesia, and operation, should be abandoned. Suggestions for the clinical assessment of lung function of patients with emphysema are given at the end of the article, together with some of the simpler tests which the anaesthetist, in hospital practice in this country, might reasonably ask for, to help with difficult cases.

DEFINITION OF EMPHYSEMA

Before describing the functional changes, we must decide "What do we mean by emphysema?" This somewhat irritating, but nevertheless pertinent, question nearly always arises in any discussion of the subject. And there is usually no real agreement as to the answer! Yet it is essential for us to be clear about what clinical entity we do refer to, so it is considered in some detail here.

The trouble seems to be that emphysema is defined from morbid anatomy and histology, in terms such as overdistension and disruption of alveoli, but owing to practical difficulties of lung biopsy, this pathological change can hardly ever be directly verified in life. From its Greek derivation, the word "emphysema" simply means "over inflation"; but the usual convention in pathology is to include in the definition only those cases in which there is some destruction of alveolar walls and their capillary blood vessels, though some pathologists have added overdistended but otherwise intact lungs, within their definition as one form of emphysema (Reid, 1958a).

Sometimes emphysema is very localized or, if generalized, of such a mild degree as to cause no detectable functional change in life and is only recognized *post mortem*. Such cases are naturally of little concern to the clinician or the anaesthetist; to them emphysema is really a functional diagnosis (Stuart-Harris and Hanley, 1958) in patients where a history of excessive breathlessness on exertion, without other cause, together with certain physical signs (see the clinical section of this symposium by Dornhorst (1958)), is assumed to have been caused by this pathological process. And most clinicians are of general agreement as to what they mean by emphysema though the physical signs are imprecise (Fletcher, 1952; Schilling et al., 1955) and the correlation with pathological diagnosis at subsequent autopsy not very high (Christie, 1944; Monroe, 1951; Hugh-Jones, 1958).

Although the meaning of emphysema clinically

could, and should, be reasonably well defined, the term is often used very loosely and added, almost gratuitously, about any breathless patient who has bronchitis, by the phrase "Bronchitis and Emphysema". In this country, where bronchitis is common, most patients with emphysema also have bronchitis and it may well be that chronic bronchitis gives rise to emphysema (Oswald, 1958; Stuart-Harris and Hanley, 1958). But many patients only have excessive bronchial secretion, with or without secondary asthma, and do not have the features of emphysema. They tend to be generally more fit than those with emphysema and hence are less often seen in hospital. They present the anaesthetist with a different and much less serious problem. In contrast, there are a few patients who appear to get pure emphysema with no accompanying bronchitis and no history of ever having had it. Such patients are probably more common in the United States, where chronic bronchitis seems to be less prevalent than here (unless the diagnosis is simply less often made). This difference between the two countries may have added to the confusion over the term "emphysema". But it is the vague use of the word to cover almost any form of chronic chest disease that is the most serious cause of confusion.

In practice we are concerned with a condition that produces changes in lung function rather than anatomical changes that can be consistently detected in life, except in extreme cases when the diagnosis is usually obvious. Thus, there seems to be much to be said for defining it in terms of functional as well as morbid anatomical change.

Quite a good parallel is diabetes, which, with the advance of biochemistry, has come to be defined in terms of change in chemical function in the body, and morbid anatomy plays a minor role. In an early textbook of medicine (Marryat, 1758) diabetes was defined as "a preternatural discharge of urine", with the patient feeling thirsty; there was no comment on the mechanisms of the lesion because biochemistry was not available and many cases were confused with urinary disorders. Emphysema might similarly be defined, clinically, as "a preternatural output of air from the lungs on slight exertion, with the patient feeling breathless". This clinical definition would be misleading, and imprecise. But just as the excessive urine production in diabetes was later understood, and the condition diagnosed precisely from other conditions causing this symptom by biochemical tests of blood and urine, so the cause of the symptoms of emphysema can be understood from the application of biophysics and biochemistry. When the tests, many of which are at present too complex for routine use, are simplified and further advanced, it is highly likely that a precise diagnosis of emphysema, and of its extent, will be possible in life. In fact, it is only in this condition that lung function tests have a real *diagnostic* value—apart from rare exceptions like the diagnosis of alveolar-capillary block (Cournand, 1952).

We shall therefore call "emphysema", in this symposium: *"a disease causing specific changes in lung function* (described later) *which are associated with specific morbid anatomical findings"* (described by Reid (1958b) in the pathology section). Specific functional changes are diagnosed from clinical history and findings, associated with functional tests (as in diabetes!). Thus we exclude from consideration those patients whose lungs are merely overdistended (because of the pathological definition), as well as those who have pathological findings which produce no demonstrable effect in life.

We may summarize the problem by commenting that (1) it is essential for the clinician (or anaesthetist) to be familiar with the functional changes revealed by complex tests if they are to interpret any purely clinical assessment with some change of success, (2) that emphysema is usually seen in this country with accompanying bronchitis and secondary asthma, though it can occur alone, and (3) that some patients with it, show more disturbance of the mechanics of ventilation with attendant dyspnoea as their most obvious feature, while others show a greater preponderance of disturbance of gas-exchange in their lungs, with cyanosis more obvious. It may well be that a subdivision of patients into definite functional types will later be possible. But in all patients most aspects of lung function are affected, and it is this which is pathognomonic, like the characteristic widespread disturbance in the nervous system in disseminated sclerosis.

A plea is made for an attempt at precise diagnosis of the presence and extent of em-

physema, with the aid of lung function tests when available, and against the loose usage of the word to include any chronic chest condition.

DIFFERENT ASPECTS OF LUNG FUNCTION

What are the many different aspects of lung function which are changed in emphysema? Unfortunately, clinical discussion often suggests that they are not commonly known, so they will be briefly reviewed as a basis for the description of the changes in emphysema.

The primary function of the lungs of any animal is to maintain the oxygen and carbon dioxide tensions in the arterial blood between narrow normal limits, in spite of large changes in these gas tensions after the blood has been utilized in different organs and returned by way of the veins. This constancy of arterial blood-gases, at all levels of muscular activity and oxygen usage, demands close contact, over a large surface area, between the blood pumped to the lung capillaries by the heart, on the one hand, and the medium surrounding the animal on the other, if rapid gas exchange is to take place by diffusion.

In fish, the interface between blood and the surrounding water is easily maintained so long as the heart pumps the blood through the gills. But in land-living animals the problem is much more complex. The lungs themselves have to take on a secondary function as an air pump, activated by movements of the chest wall, in order to bring fresh air into contact with the blood in the lung capillaries.

Thus there are really three main divisions of lung function:

(1) Those of the air pump (ventilation).
(2) Those of an air-blood interface (gas distribution and exchange).
(3) Those of being part of the blood pump (pulmonary circulation).

These three divisions are closely interlinked. It is, however, important for clear thought, and for practical testing, to deal with them separately. Thus, there is no satisfactory single "test of lung function" any more than there is a single test of liver or kidney function, which will deal with every case.

It so happens that patients notice, and therefore complain of, inadequacy of ventilatory function more than the others, because of the sensation of dyspnoea it produces. It is also the simplest function to measure. Hence tests for it are the only ones that have been at all widely used in clinical medicine. Defects of distribution of lung gases or circulation are rarely painful, though they may contribute to dyspnoea. Moreover, defects in these aspects of lung function may be advanced before their clinical feature, cyanosis, is detectable. Tests for these aspects are more complex and therefore less familiar than those for ventilation; nevertheless, they are of great importance in anaesthetics and are markedly abnormal in severe emphysema.

In the past, human respiratory physiology has often stopped short of descriptions of changes in lung volumes, and many medical students still learn "lung function" from preclinical studies only in terms of vital capacity (V.C.), complementary and supplementary air! Even most of the names are archaic (Pappenheimer, 1950). Although measurement of the *total volume of the lungs* (and its subdivisions) is often useful, it is really an anatomical measurement of size. Its main functional importance is when a reduced V.C. means a diminished stroke volume for the air pump, or there is a greater residue of air left at the end of the stroke.

The important concepts of ventilation are first, the *ventilation* (or "air output" and intake) *required for a given amount of activity or oxygen usage.* This is comparable to thought in terms of cardiac output or urinary output in other branches of medicine. The second concept is the maximum that the "air pump" can deliver, or *maximum breathing capacity* (M.B.C.) (which is the greatest amount of air that can be breathed per minute) as an indication of the ventilatory reserve available for exertion.

The last concept of ventilation is in terms of the *mechanics of breathing* which is concerned with the force needed to expand the lungs and to drive air in and out. Excessive force, giving rise to an increased work of breathing, is probably important in producing the sensation of dyspnoea (Marshall et al., 1954; Davis et al., 1956). There are two main components of the force required; the first is the change in intrathoracic pressure to produce a given change in the volume of the lungs (measured when air flow has ceased). This measures how stiff the lungs are,

though the results are usually expressed as the reciprocal of stiffness, that is, the *compliance*, or how "easy" it is to increase their volume (volume change per unit pressure change). The second is the extra force required during movement to overcome the friction of air flow in the bronchial tree (and partially from movement of intrathoracic viscera). This is the *nonelastic resistance* (pressure per litre/sec of air-flow). At the beginning of inspiration, before air flow begins, the intrathoracic pressure drop is zero; it reaches a peak at the maximum rate of movement of the lungs, and then decreases to zero at full inspiration when movement stops. This extra intrathoracic pressure drop required during lung movement for nonelastic work thus depends both on the rate of breathing and the resistance offered to movement, mainly as "airways resistance".

Coming to the second main division of lung function, one realizes that not only must the total ventilation in the lungs be adequate for a given level of activity, but the air must be distributed evenly to the myriad of alveoli in the lung through which the blood is flowing, if the primary purpose of the lung in maintaining the normal gas tensions of arterial blood is to be fulfilled. Thus we are concerned with any *inequality of gas distribution.* Since the pioneer work of Rahn (1949), Riley and Cournand (1949) and other "clinical respiratory physiologists", mostly in the United States, it has been realized that the significance of maldistribution of gas depends on the relative distribution of blood. To take an extreme case of all the ventilation going to one lung and none to the other; the patient is not seriously incapacitated if the unventilated lung has no blood flow, he simply has a "pneumonectomy"; but if normal blood flow continues in the unventilated lung, he has serious disturbance of the gas tensions in his arterial blood and, at the other extreme, if the air flow goes to one lung and the blood flow to the other, he would be dead! Such lack of balance between air and blood flow may occur in individual alveoli. Ventilation of unperfused alveoli means wasted ventilation or increased "physiological deadspace"; perfusion of under- or unventilated alveoli means some "venous admixture" or total "shunt". Thus it is different *ventilation-perfusion ratios* throughout the lung which really matter, rather than maldistribution of gas. Provided overall ventilation is adequate and there is no barrier to the diffusion of gas in the form of a thickened alveolar membrane, then the summation of different ventilation-perfusion ratios throughout the lung alone determines the gas tensions in arterial blood when mixed venous blood of a given composition has traversed the lung.

Finally, in this second main division of lung function, there is the problem of any interference with gas diffusion, because of change in the structures which lie between the alveolar gas and the blood; namely, alveolar membrane, capillary wall, plasma, and red-cell membrane. Any interference with diffusion is measured by the *diffusing capacity* of the lung. Since gas flow to or from the blood into alveoli by diffusion simply depends on whether the gas is at a higher pressure in blood or alveoli respectively, and since the rate of flow depends on the magnitude of the pressure difference between the two, the diffusing capacity for any gas, is that quantity which passes per minute from alveoli into blood for each mm Hg pressure difference across the interface. But this quantity, for the whole lung, will depend not only on the resistance to diffusion at the interface, but also on the size of the interface which represents the surface area of the lung available for diffusion; this is a function both of the size of the lung itself, and of any lack of balance between ventilation and perfusion which may effectively reduce the interface. Thus, the overall diffusing capacity of the lung which is measured in practice, is a rather mixed, though useful measure of "the gas exchange capacity of the lung".

The third main division of lung function, that of the lung circulation, entails concepts of cardiac output and pulmonary artery pressure. These concepts have already become, in "cardiology", an accepted part of clinical medicine, unlike those of the other two divisions.

Table I summarizes this discussion of lung function, by showing the seven aspects which can, and should be tested, in the full functional assessment of a patient with respiratory disease. For reference, the methods used are indicated in parenthesis in the table. They, like their theoretical basis, are almost all fully described in the excellent book on the clinical physiology of the

TABLE I

Some Aspects of Lung-Function which can be tested in a full Investigation of a Patient with Emphysema or other Respiratory Disease.

(A) THE LUNG AIR-PUMP FOR VENTILATION

(1) *Total Lung Capacity and Subdivisions.*
(By closed circuit spirometry, with helium dilution technique; or by open circuit nitrogen wash out; or whole-body plethysmograph.)

(2) *Ventilation at Rest and Standard Exercise (or known Oxygen Consumption).*
(Using low-resistance gas-meter, or "anemometer", to measure ventilation and standard step-test, bicycle ergometer or tread-mill.)

(3) *Maximum Breathing Capacity.*
(Either directly from Maximum Voluntary Ventilation test or indirectly from Forced Expiratory Volume in 1 second.)

(4) *Mechanics of Breathing:*
(a) Compliance.
(b) Nonelastic Resistance.
(By relating intra-oesophageal pressure, as a measure of intrapleural pressure, to change in lung volume and air flow; or whole body plethysmograph; or air flow interruptor.)

(B) THE LUNG FOR GAS DISTRIBUTION AND EXCHANGE

(5) *Inequality of Gas Distribution.*
(From analysis of a single expiration using rapid analyzer for inert gas, e.g. nitrogen meter or mass spectrometer; or from multiple breath washing-out of lungs.)

(6) *Ventilation-Perfusion Relationship.*
(From analysis of arterial blood gas tensions, using the bubble syringe technique; or from alveolar gas tensions using a mass spectrometer.)

(7) *Diffusing Capacity at Rest and Maximum diffusing Capacity on Exercise.*
(For carbon monoxide either by a single-breath or multiple-breath "steady-state" method; or for oxygen using low oxygen breathing and analysis of arterial blood gas tensions.)

lungs by Comroe et al. (1955), to which the reader is referred for details. The list in table I is not exhaustive, other tests (such as bronchospirometry), and other methods than those listed, are used for special purposes; but it will serve as a framework for the description of the changes in emphysema. Those of pulmonary circulation itself are omitted; not because they are any the less important, but because they usually come within the sphere of cardiology.

The reader is referred to the previous postgraduate educational number this journal (Campbell, 1957) for definitions of any of the standard terminology and symbols which will be used.

CHANGES IN EMPHYSEMA

Total Lung Capacity and Subdivisions.

Observations. In most subjects with emphysema, but not all, the total lung capacity is increased compared with a normal man of the same age. A more constant feature is an increase in both the resting volume of the lungs or functional residual capacity (F.R.C.) and the volume of air that remains in the lungs at the end of a forced expiration (residual volume) (see fig. 1). The residual volume is not only increased absolutely, but it forms a greater percentage of the total lung capacity, compared with normal.

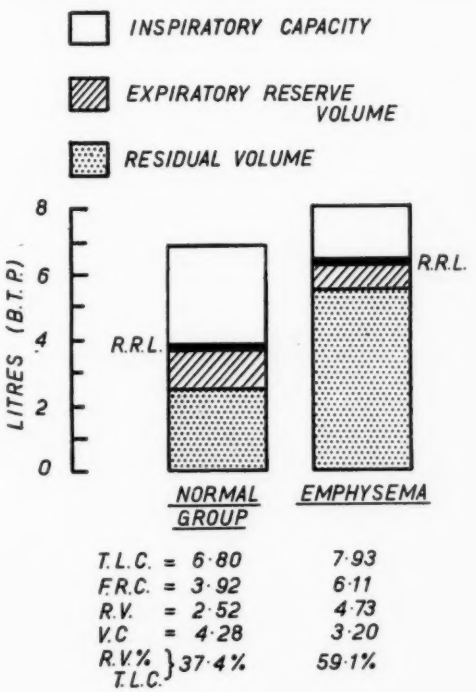


FIG. 1

Histogram showing the average values for the total lung capacity, and its subdivisions, in a group of five subjects with advanced emphysema (average age 52 years) contrasted with a comparable group of ten normal subjects (average age 54 years). Coefficient of variation approximately 20 per cent for all readings in both groups. (From Gilson and Hugh-Jones, 1955.)

In this country the closed-circuit method using helium as the indicator gas, is usually used to measure the total lung capacity. Its results agree fairly well (Gilson and Hugh-Jones, 1949) with the open-circuit method often used in the United States. During its use a tracing of resting ventilation (spirogram) is usually recorded together with the V.C. Such tracings are fairly characteristic in severe cases of emphysema (fig. 2). Not only is the V.C. reduced but the time taken to record it is much prolonged, thus, the tracing has a curved appearance, especially at the end of the expiration, when a long time is taken to expel the last small volume of air. Further, the original relaxation level (resting respiratory level) is not reached again until after a number of breaths, especially after measurement of the inspiratory capacity ("trapping", see later).

Clinical and pathological significance. In normal breathing with the subject at rest, inspiration is the only muscular action. Expiration is passive and occurs by use of the elastic energy that was stored in the lung when it was stretched in inspiration. Expiration continues until the elastic recoil of the lungs, tending to pull inwards, balances the tendency of the thoracic cage to spring outwards. (If a hole is made in the chest wall these forces no longer balance; the chest wall springs out and the lungs continue to retract, resulting in a pneumothorax.) Thus the lowest points on a spirometer tracing of normal breathing lie along a line, since the lungs return to the same resting respiratory level (R.R.L.) determined by this balance at each breath, and the F.R.C. remains constant. The upper points on the tracing depend on the muscular contraction applied for a given breath and are less regular (fig. 2) Tidal ventilation is increased on exercise mostly by increasing the depth of active inspiration, though there is some active muscular expiration so that the R.R.L. may change. The V.C. is some indication of the maximum available stroke volume of the lungs as an air pump.

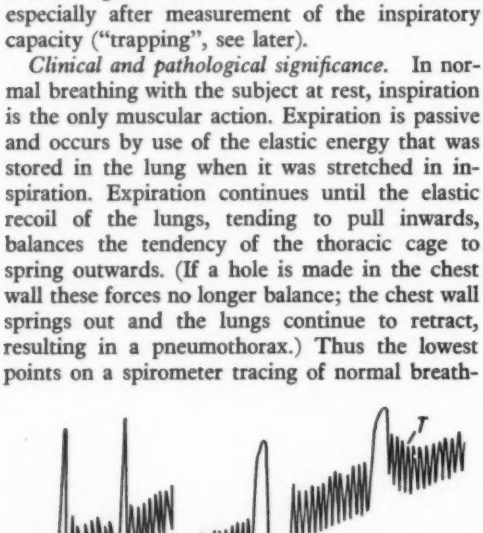


FIG. 2

Spirograms, redrawn from current recordings, which are typical of those for normal subjects and for advanced emphysema. *Note*: evidence of "air-trapping" in expiration (T) and the rounded end of the full expiration curve (E). The latter is better seen from a tracing in a fast-moving spirometer and drum, as in figure 3.

In emphysema, much of the elastic recoil of the lungs is lost; this raises the R.R.L. and increases the amount of air in the lungs at the end of expiration (F.R.C.). When the thorax is opened the lungs will not collapse as far and the patient's chest is held in inspiration and may become "barrel-shaped". However, many patients with gross emphysema have thin chests, and the increased F.R.C. cannot easily be appreciated without measurement.

The V.C. is reduced, but even then it gives a falsely large impression of the maximum effective stroke volume, because of the length of time required to expel the full capacity. This and the trapping of air (discussed more fully later), which is seen on the spirogram, are why the V.C. is an unsatisfactory estimate of the ventilatory reserve in emphysema.

Although these changes in lung-volume measurements are characteristic of emphysema they are not, of themselves, diagnostic. A patient with spasmodic asthma, who has no emphysema at all, will give practically the same results on spirometry. Some differentiation between the two conditions will be seen by repeated tests after antispasmodic treatment, and emphysematous patients will also show changes in other aspects of lung function as well, which are not characteristic of asthma. Taking a raised value for the residual volume, expressed as a percentage of the total lung capacity, as being synonymous with emphysema (Motley and Lang, 1948) is erroneous. This percentage is raised in emphysema, but it bears no relation to the severity of the condition and correlates badly with general lung function (Baldwin et al., 1949). Further, it is raised, not only in asthma, but in many fibrotic conditions of the chest (which are functionally

entirely different), not because of an increase in absolute residual volume but because of a reduction in inspiratory capacity and total lung capacity (Gilson and Hugh-Jones, 1955).

Ventilation Required for a Given Oxygen Uptake.

Observations. The group of five patients with advanced emphysema, shown in figure 1, had an average resting ventilation of 9.5 l./min. The corresponding group of normal subjects had an average resting ventilation of 8.4 l./min. When each group exercised at the same rate of work (350 kg.m/min) for 5 minutes they required a ventilation of 30.8 and 27.6 l./min respectively —the exercise ventilation quoted being "standardized" (Hugh-Jones and Lambert, 1952) to minimize the effects from some of the subjects being unable or unwilling to complete the full 5 minutes of exercise. These figures, in spite of the inaccuracy and difficulty in making such measurements (see later), fit in with the experience of most workers that even at an advanced stage of emphysema the patient's resting ventilation is only slightly increased above normal in spite of dyspnoea or breathing distress. Only at the most advanced stage, with marked cyanosis on exercise, is the exercise ventilation much increased.

Comments. It must be appreciated that the significance of any measurements of ventilation, particularly at rest, is always doubtful because the use of mouthpieces, valve-boxes or spirometers, may promptly cause psychological hyperventilation. However, the comparison of measurements made under the same conditions, between corresponding groups of emphysematous and normal subjects is probably valid even though the absolute values are less reliable.

Normally, the lung alveoli are ventilated with fresh air in sufficient quantity to dilute the carbon dioxide produced so that its partial pressure is 40 mm Hg (within narrow limits).

This fundamental relation is expressed by the equation:

$$P_{CO_2} = \frac{0.863 \times \dot{V}_{O_2}.R}{V_A}$$

where the constant 0.863 is simply the correction factor for temperature, pressure, and water vapour, and the product $\dot{V}_{O_2}.R$ (oxygen consumption × respiratory quotient or R.Q.), is the carbon dioxide produced per minute which, for a given R.Q., depends on the patient's activity as reflected by his oxygen consumption. Thus the alveolar carbon dioxide tension ($P_{A_{CO_2}}$) varies directly as the oxygen consumption but inversely with alveolar ventilation. If alveolar ventilation is increased, as in voluntary overbreathing, without an increase in metabolism, the arterial P_{CO_2} falls. Increase in ventilation accompanied in this manner is defined as *hyperventilation.* Conversely, reduced alveolar ventilation without a decrease in metabolism, as in obstruction to breathing, causes hypercapnia and *hypoventilation.*

There is no pressure gradient between alveolar and end-capillary carbon dioxide in any alveolus; the respiratory centre is very sensitive to changes in arterial carbon dioxide tension ($P_{A_{CO_2}}$) and readily adjusts the ventilation accordingly. The critical amount of this ventilation is the fresh air entering the alveoli and not that entering the nose or mouth. About a quarter or a third of the latter goes no further than the upper respiratory passages where no gas exchange takes place ("anatomical deadspace"). In emphysema this deadspace effect is increased, and an abnormally large proportion of inspired gas takes no part in alveolar gas exchange, because of ventilation of unperfused alveoli.

Thus, when a patient with severe emphysema has a total ventilation at rest but little raised compared with a normal subject, it is often found that this alveolar ventilation is inadequate and is raised above normal. If the $P_{A_{CO_2}}$ is, say, 60 mm Hg, his alveolar ventilation is only two-thirds of that required to maintain the normal 40 mmHg. In other words a "normal" figure for ventilation may mean hypoventilation in an emphysematous subject whose physiological deadspace is raised. This is most important for the anaesthetist and physician to remember, especially when using artificial mechanical ventilation.

Some emphysematous patients do increase their ventilation for a given state of activity enough to overcome the increase in deadspace caused by the lack of balance between ventilation and perfusion of their lungs. They ventilate excessively, compared with normal subjects, and tend to complain of dyspnoea. Others, as it were, give up the struggle of dyspnoea and "settle" for inadequate ventilation and a raised $P_{A_{CO_2}}$ even at

rest. This would suggest that their respiratory centre becomes rather insensitive to carbon dioxide (Donald and Christie, 1949; Prime and Westlake, 1954). However, recent studies (Cherniack and Snidal, 1956) show that introduction of some obstruction in the airways of a normal subject decreases his response to carbon dioxide; vice versa, relief of respiratory obstruction increases the response to carbon dioxide in emphysema. A major factor in the failure to increase the resting ventilation adequately, with the enlarged physiological deadspace in emphysema, is probably the altered mechanics of the chest. Increased ventilation would necessitate excessive work of breathing and there are stretch receptors for the lungs which provide signals related to the work of breathing (Davis et al., 1956). It seems that the "discomfort" from excessive stimulation of stretch receptors may be greater than that from excessive stimulation from carbon dioxide! However, the role of the stimulus to the respiratory centre by carbon dioxide and anoxia is important, and its significance relative to mechanical factors (Fishman et al., 1955) is still under review (see Nunn (1958), under Carbon Dioxide Narcosis).

There appears to be less ventilation on exercise in those emphysematous patients who have a raised alveolar and arterial carbon dioxide at rest than in those where it is normal (Donald, 1953). Usually, the increase in exercise ventilation in emphysema is small compared with the enormous increase which occurs in patients with various types of pulmonary infiltration which produce a reduced diffusing capacity for oxygen. For example, on the standard exercise test cited previously, two patients with xanthomatosis of the lungs had standardized ventilation of 69 and 76 l./min respectively, compared with the normal of about 27 l./min and more than twice that of subjects with advanced emphysema. Exercise ventilation is really excessive only in severe emphysema, with marked exercise cyanosis, and then it causes great distress because of the small maximum ventilation that the subject with emphysema can produce (see later).

In summary, hypoventilation occurs in many emphysematous subjects, even at rest, largely because of mechanical obstruction to breathing. This hypoventilation is often present when the total ventilation from the nose or mouth is normal or even increased, for a given metabolism. This is because there is extra "alveolar deadspace" (total physiological deadspace minus relatively constant anatomical deadspace of upper airways) caused by the presence of alveoli which are ventilated but not perfused with blood.

Maximum Breathing Capacity.

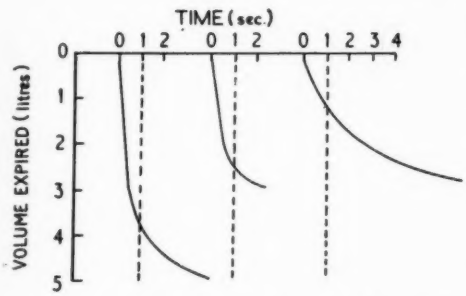
Observations. When the group of our five subjects with advanced emphysema were asked to breathe in and out both as deeply and as fast as possible for 15 seconds, the depth and rate being recorded in such a way as to ensure the optimum combination to produce the maximum ventilation (direct method of recording the M.B.C. by maximum voluntary ventilation test), their average "best" was 25 l./min compared with an average of 120 l./min for the normal group of men of the same age.

The results of this test are not, as might be expected, largely a function of the patient's incentive to do the test. With a competent observer, the results are reasonably repeatable, and any defect in repeatability (compared with a V.C. test) are repaid in the big differences there are to measure between normal and diseased subjects. It is like using a coarse ruler to measure a long distance, rather than a fine one for a short distance.

But the performance of maximum voluntary ventilation is an uncomfortable and possibly dangerous procedure, especially in ill patients. One breath is very like another and the relation of inspiratory pattern to expiratory pattern is sufficiently fixed (Bernstein and Kazantzis, 1954) for it to be found that the M.B.C. can be predicted with remarkable accuracy from the volume of gas exhaled in a given time during a single forced expiration; the correlation between the two being of the order of $r = 0.9$ (Tiffeneau et al., 1949; Kennedy, 1953; Kadlec and Vyskocil, 1950). The measurement of this volume is a very simple procedure for the subject; it merely entails taking in as deep a breath as possible and exhaling it as forceably and rapidly as possible into a suitable spirometer. The volume exhaled in a given time, usually 1 second from the start of the expiration, is then recorded either from a spirometer tracing or by an automatic timing device

(Gaensler, 1951). This volume is known as the forced expiratory volume in 1 second, or F.E.V.$_{1.0}$ in the terminology agreed in this country (Gandevia and Hugh-Jones, 1958). The F.E.V. in litres, when multiplied by a suitable factor (which is 35 for the F.E.V.$_{1.0}$) gives an indirect measure of the M.B.C. in litres/minute. This multiplication of the test results by a constant factor is, of course, unnecessary, and the F.E.V. itself is as good a measure of the patient's maximum ventilation as this indirect M.B.C.; the only justification for it is that the normal values for the M.B.C. are more familiar to most clinicians.

Measurement of the F.E.V. has been described in detail because it is a test simple enough for routine use by anaesthetists, for helping them to assess a patient before operation. A typical tracing from a patient with emphysema (fig. 3) contrasted with that from a corresponding normal subject, shows that although the vital capacity



	A. Normal Subject	B. Ankylosing Spondylitis	C. Asthma & Emphysema
F.V.C. (litres)	4·90	2·90	2·90
F.E.V.$_1$ (litres)	3·90	2·60	1·20
Ind. M.B.C. (litres/min.)	136	91	42
F.E.V. %	80	90	41

FIG. 3

Tracings recorded when measuring the F.E.V., showing a comparison of the normal, with those from patients with ankylosing spondylitis (as an example of a purely "restrictive" chest lesion) and emphysema (mainly "Obstructive" lesion). *Note*: as the spirometer bell rises the recording pen falls, so that the expired volumes are traced downwards. (From Thomson and Hugh-Jones, 1958.)

is fairly reduced the F.E.V.$_{1.0}$ is reduced by a disproportionately great amount, and forms only 30 per cent of this reduced vital capacity, compared with a normal value of about 80 per cent when there is no obstruction to air flow. Thus a low F.E.V.$_{1.0}$ as percentage of the V.C. means air-flow obstruction. In diseases where there is restricted chest movement, but no air-flow obstruction, as in ankylosing spondylitis, the F.E.V.$_{1.0}$ is reduced, and hence the M.B.C. is reduced, proportionately to the reduction in V.C., and the shape of the expiratory flow curve is normal.

Thus in emphysema, there may be gross reduction in the M.B.C.

Clinical significance and comments. Even in normal subjects a sensation of distress in breathing comes on with increasing ventilation on exercise; it becomes acute in most subjects, as the ventilation exceeds about 60 per cent of their M.B.C., though there is a wide threshold of distress. Emphysematous patients, then, have a lowered ventilatory reserve for exercise, because of their reduced M.B.C. When this drops to levels below about 20 l./min, they can do no more than walk very slowly on the level, and even this produces severe dyspnoea.

This low M.B.C. results from having a small stroke volume of their "air pump" as well as obstruction to air flow, particularly on expiration. Most patients who have emphysema have some bronchitis, and asthma as well; in them some of this air-flow obstruction is asthmatic "bronchospasm", and this can be relieved by antispasmodics. The F.E.V.$_{1.0}$ will then increase if it is remeasured after 5 minutes inhalation of an aerosol containing isoprenaline or adrenaline and atropine compound (B.P.C.). But much of the air-flow obstruction in emphysema appears to be caused by the loss of elastic recoil in the lungs and bronchial walls; it is therefore permanent (see later, under Mechanics of Breathing). In patients with pure emphysema without secondary asthma, there will be no change in the F.E.V. after aerosol or other antispasmodic treatment.

It is important to note that the forced vital capacity tracings of a patient with spasmodic asthma, and no emphysema, will, during an attack, be identical with those of a patient with emphysema. If after continued antispasmodic

treatment, the F.E.V. as a percentage of the V.C. rises to normal levels (greater than about 75 per cent), the patient has no emphysema, but other tests than the F.E.V. are needed to distinguish emphysema from asthma, which is resistant to treatment, when the F.E.V. percentage remains low. Even in spasmodic asthma the F.E.V. percentage may not initially increase during successful treatment, in spite of marked improvement in the absolute $F.E.V._{1.0}$, because the V.C. increases concurrently and the percentage remains the same (Thompson and Hugh-Jones, 1958).

In patients with asthma the inspiratory flow is reduced as well as the expiratory flow so that the difference between the forced inspiratory volume, in a given time, and the F.E.V. will be less than in patients with pure emphysema, in whom there is relatively little inspiratory air-flow resistance compared with that in expiration (Campbell, 1958a). A very low F.E.V. percentage means either untreated asthma or emphysema; an F.E.V. percentage persisting very low despite energetic treatment of asthma is highly suggestive of emphysema. Measurement of the F.E.V. is of great use to the anaesthetist in the assessment of ventilatory capacity in emphysematous patients before operation and in the detection of asthma.

Mechanics of Breathing.

Observations. When changes in intrapleural pressure (which, in practice, are usually measured as changes in oesophageal pressure) are plotted against change in volume of the lungs during quiet breathing the type of curves obtained for normal and emphysematous subjects are shown in figure 4. At the instants of air-flow reversal, at full inspiration (Y) and expiration (X), the air-flow is zero, so the slope of the line X–Y represents the compliance of the lungs or the static volume change per unit change in intrapleural pressure. If measured during slow breathing there is often little change in this in emphysema, though there is a tendency for the lungs to be more compliant, that is the line X–Y is steeper than normal. In other words, the lungs tend to increase in volume more than they normally would for a given pressure change and, conversely, for a given volume of distension they exert less recoil pressure (Mead et al., 1955; Campbell, 1958a).

In practice, with the rapid breathing which is

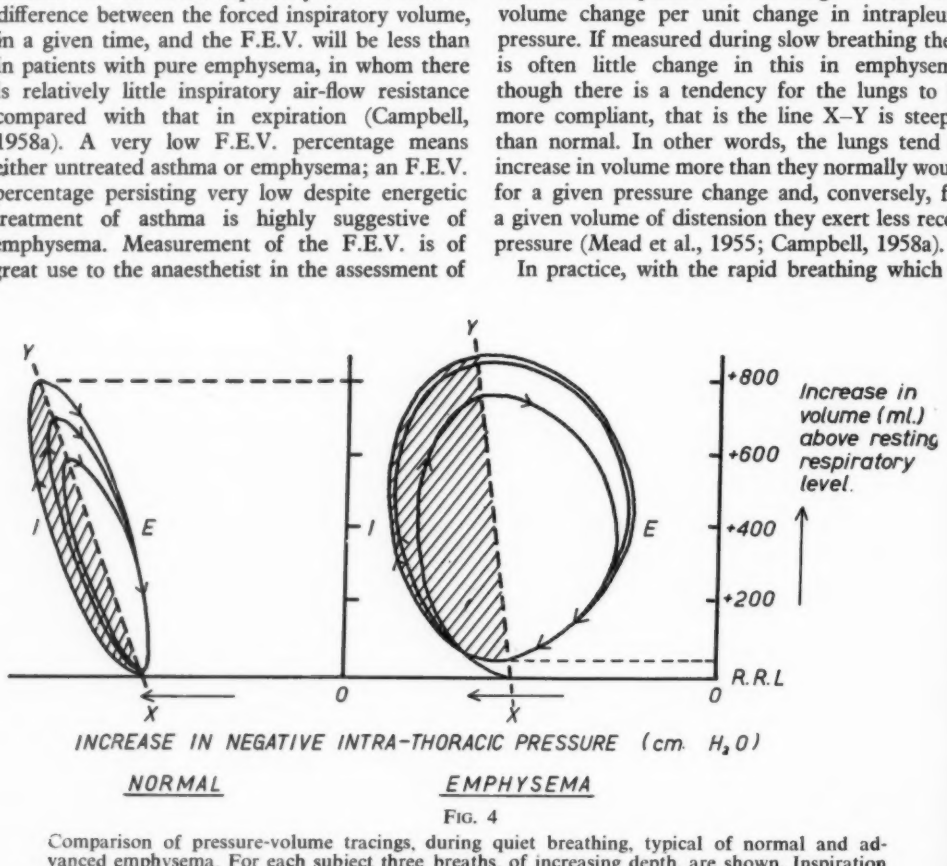


FIG. 4

Comparison of pressure-volume tracings, during quiet breathing, typical of normal and advanced emphysema. For each subject three breaths, of increasing depth, are shown. Inspiration (I) and expiration (E); arrows show direction of change with breathing; X and Y are the points of zero air flow at the end of expiration and inspiration, respectively. (Redrawn from oscillograph records and the work of Mead et al., 1955, and Campbell, 1958b.)

often present in emphysema, some parts of the lungs fail to fill in the time available. The points of air flow reversal, X and Y, are not those of zero flow and the line X–Y does not represent the true static compliance line for the whole lung. In these circumstances the lungs appear to get stiffer, the faster the breathing rate at which "compliance" is measured (Cherniack, 1957) as the volume change which has taken place by the time of flow-reversal, for a given pressure change, is less than it would be had a long time been available. The "compliance" measured in such circumstances is called "dynamic", rather than the true "static" compliance.

Work is represented as areas on the pressure-volume diagram, and the extra force (above that required to hold the lungs at a given volume) which is needed to move the air into the lung is shown by the hatched area on the side of the line X–Y. It increases as flow rate increases, so that the loop gets wider as breathing becomes faster. From these curves, pulmonary flow resistance can be expressed as the pressure necessary to produce a given rate of flow. During quiet breathing Mead et al. (1955) found the resistance in emphysematous patients to be especially increased in expiration, with the well-known prolongation of the expiratory phase of breathing. In their example (fig. 5), the patient accomplished a flow of 0.2 l./sec, early in expiration, at a cost of little more than 2 cm of water, but later it was

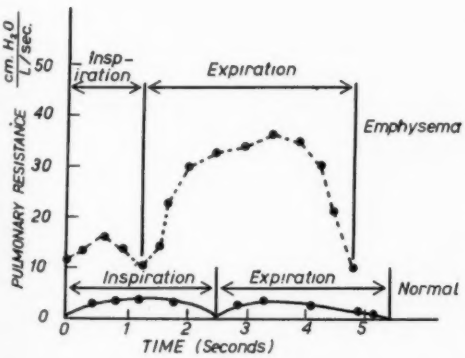


FIG. 5

Comparison of the pulmonary air-flow resistance in a normal and an emphysematous subject. (From Mead et al., 1955.)

vastly increased compared with normal. On hard breathing this patient had tremendous airways resistance: "while applying a pressure difference of more than 80 cm of water to his lungs and airway, the rate of flow was only 0.5 litres or of the order of magnitude encountered during normal resting expiration where the resistance pressure would be less than 1 cm of water in normal individuals".

Comments and clinical significance. The increased compliance reflects the loss of elastic recoil. But it is the enormous expiratory resistance which is the main problem and this is bound up with the loss of recoil. Expiration is normally passive and the recoil pressure of the lungs, as it drives the air up the airways, maintains the pressure in them above that of the surrounding intrapleural space (Campbell, 1958a). This recoil is largely lost in emphysema. Any increase in intrapleural pressure from the use of expiratory muscles in an attempt to accelerate the air flow, simply narrows the airways and tends to produce "trapping" (Attinger et al., 1956). It is this which results in the enormous expiratory flow resistances seen on forced expiration. Campbell et al. (1957) have measured the maximum intrathoracic pressure which produces the maximum flow and found it greatly reduced in emphysema compared with normal subjects.

Thus, the flow resistance in emphysema is not bronchospasm. It is a different mechanism from that in asthma where the resistance is raised in inspiration as well. Trapping does occur in normal subjects but only at the end of a forced expiration, which it limits. In emphysema it tends to occur at the very start of expiration, when the chest is still high in the inspiratory position, if the slightest effort is made by the subject to increase his rate of airflow by the use of expiratory muscles.

The work of breathing may become so great in severely emphysematous subjects that the oxygen consumption of the respiratory muscles may be a high proportion of the total (Campbell et al., 1957), and any increase in ventilation or exercise would mean an oxygen cost of breathing greater than the extra oxygen intake. If such patients perform hardly any exertion their breathing distress is appalling.

Perhaps it is not surprising, considering the

mechanics of their lungs, that emphysematous subjects often do not maintain the alveolar ventilation required to avoid carbon-dioxide retention, especially with their increased physiological deadspace. To make matters worse, some elderly subjects with emphysema may have increased stiffness of their chest walls which we have not considered, since the intra-oesophageal balloon only enables us to measure lung compliance. The inspiratory muscles then contract against a relatively rigid wall and produce a small change in intrapleural pressure. Finally, the static lung compliance, after being increased, may eventually become reduced in emphysema, when cor pulmonale sets in; and the lungs become turgid with fluid (Cherniack, 1956).

All these mechanical factors are of importance, not only in understanding the functional lesions of emphysema, but to the anaesthetist in practice. For example, in artificial mechanical ventilation of an emphysematous patient with extreme hypoventilation and carbon dioxide retention, the ventilation may have to be very slow, and as deep as practicable to achieve the required alveolar ventilation, and the negative pressure phase used with care if trapping and dangerous resistance to air flow is to be avoided.

Lastly, the inequality of gas distribution in emphysematous lungs, which is described below, is probably largely dependent on their mechanical properties (Otis et al., 1956); and ventilation at different rates will alter this gas distribution by a mechanism illustrated in figure 6. Pask (1958) has recently produced a model to demonstrate this point.

Inequality of Gas Distribution.

Observations. It has long been known that it takes a much longer time to "wash out" all the nitrogen from the lungs, by breathing pure oxygen, in patients with emphysema than it does in normal subjects. Thus after breathing oxygen for 7 minutes, a patient with emphysema may have about 7 per cent of nitrogen in his expired gas instead of about 2 per cent as in normal subjects. This is partly because of the large functional residual capacity of emphysematous patients; but by following the pattern of washing out of the nitrogen it can be shown that uneven distribution of gas to the different regions of the

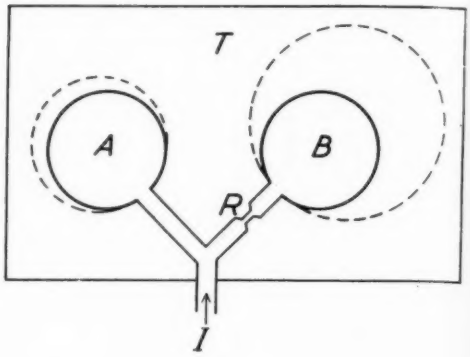


FIG. 6

A and B are any two units of the lung in a thorax T. Unit B is more compliant than A, but there is a greater resistance (R) in the airway to it. If the pressure in T falls slowly, B will become bigger than A because of its greater compliance. If it falls quickly, however, A will become bigger than B, because the resistance R, will slow the rate of filling of B.

lung contributes to this slow process of gas replacement in emphysema (figure 7). Were the inspired oxygen evenly distributed the breath-by-breath changes of expired alveolar nitrogen concentration would be on a straight line when they were plotted on a logarithmic scale against the number of breaths, on a linear scale. The slope of this line is dependent on the tidal volume and F.R.C. In normal subjects the points nearly do lie on such a line; in emphysema they are markedly curvilinear, the lung behaving as if the nitrogen is replaced in some parts of the lung far more rapidly than in others (Fowler, 1949; Gilson and Hugh-Jones, 1955). A similar principle can be used with a closed-circuit spirometer to give an index of "mixing efficiency" (Bates and Christie, 1950).

An alternative and simpler procedure, when a rapid-recording automatic nitrogen analyzer is available, is to observe the change of concentration of alveolar nitrogen per unit volume exhaled, following a single inspiration of oxygen (Comroe and Fowler, 1951). At the end of a normal expiration the subject simply inhales one deep breath of oxygen. He then exhales and the gas is continuously analyzed for nitrogen content. First, nitrogen-free gas comes from the anatomical deadspace; then a plateau of alveolar gas is seen

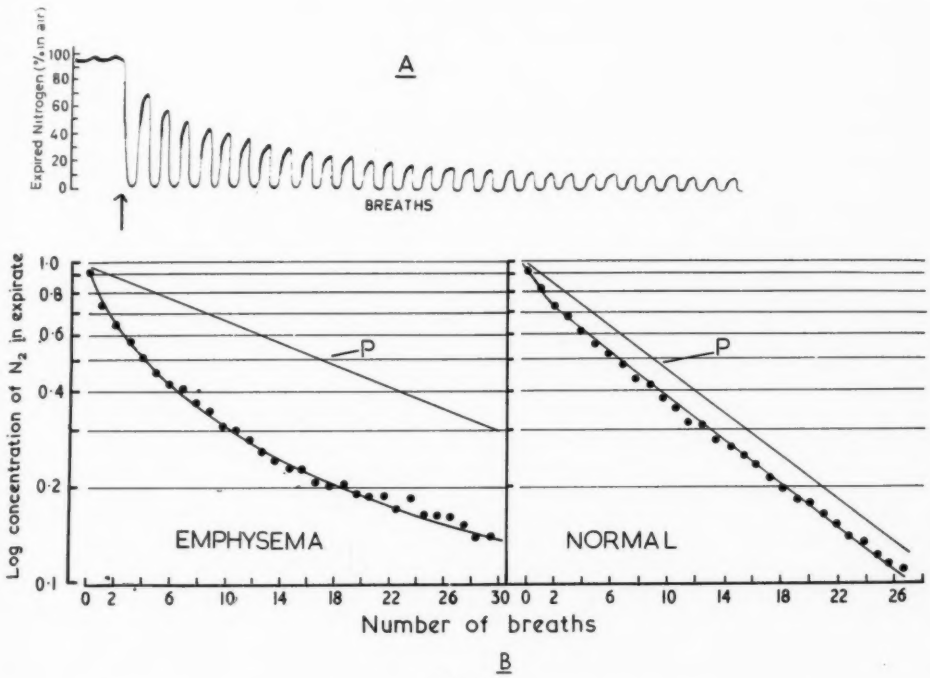


FIG. 7

A is a record of the process of "washing-out" the nitrogen in the lungs by breathing oxygen. The concentration of nitrogen in the expired gas leaving the lips (measured with a mass-spectrometer) is followed, after the start of breathing oxygen at the point marked by the arrow. *B* is the results from *A*, in an emphysematous compared with a normal subject, with the expired alveolar nitrogen concentration plotted logarithmically against the number of breaths. The straight line (P) would be followed in perfectly even gas distribution, with the particular tidal volume and F.R.C. of the subject. (From Fowler and Hugh-Jones, 1957.)

on the tracing. Well-ventilated alveoli, in which the nitrogen has been well diluted with oxygen, empty early in expiration, and poorly ventilated ones, whose nitrogen concentration will be higher, empty late. In normal subjects there is little change in nitrogen concentration between the beginning and end of the alveolar plateau. But in emphysema there is a steep rise in alveolar nitrogen, thus revealing the uneven ventilation in emphysema from the different dilution of nitrogen by the oxygen in different groups of alveoli.

The principle of this test should be clear from curve 3 of figure 8, which is the same test "in reverse". The patient inhales a single breath of air containing argon (which is inert) and the subsequent long exhalation is continuously analyzed for its argon content by using a recording mass-spectrometer.

Comments. Marked inequality of gas distribution may be seen in emphysema and it is helpful diagnostically. Its functional significance depends on the relative distribution of the blood (see later). It should be noted that the single-breath method detects the regional inequality of ventilation only in so far as groups of alveoli with different ventilation empty consecutively. If all emptied simultaneously, throughout expiration, the alveolar plateau would be flat, whatever the regional variations in gas dilution. In practice, the emptying is asynchronous, the well-ventilated alveoli emptying before the poorly ventilated ones, and the increase in nitrogen concentration

during the alveolar plateau is marked in advanced cases of emphysema, compared with normal subjects.

Ventilation-Perfusion Relationship.

Observations. In normal subjects air appears to be almost equally distributed to all the different alveoli so that the ventilation of each is practically the same. We have shown that if, in disease, the ventilation is uneven, then the significance of underventilation of some areas of the lung is negligible if the blood flow through those areas is reduced by exactly the same amount, compared with underventilation when the blood flow is normal or increased. In the former case the arterial gas tensions will be normal and the lung, in effect, will simply have lost some of its enormous surface area (and it has a large reserve for diffusion of oxygen in exercise), whereas in the latter case, the arterial blood gas tensions will be distributed; the body is thus much more affected by the blood and gas distribution being "out of step" in the lungs than by inequality of either, if the proportionate distribution of the two is the same. Just as the ventilation-perfusion ratio determines the gas tensions in the blood leaving an alveolus so it determines those in the gas expired. Any lack of balance can therefore be observed either from blood analysis or alveolar gas analysis.

The first approach to measurement of ventilation-perfusion inequality was largely through blood gas analysis (Riley and Cournand, 1949).

The principle is that alveoli with balanced air and blood flow were considered "ideal", and they had defined alveolar gas tensions and contributed arterialized blood to the pulmonary vein with normal tensions. If an alveolus has its ventilation-perfusion ratio reduced it takes up less oxygen than would be required to bring it to the "ideal" value. Its contribution to the arterial blood per unit time can be regarded as equivalent to X ml of "ideal" blood and Y ml of "shunted" mixed venous blood ("venous admixture" effect).

Now the gas-exchange ratio (R.Q.) relates the quantities of carbon dioxide excreted and oxygen absorbed in the alveolus, and the quantity of each is determined by the difference in amount between that in the inspired and that in the alveolar gas:

$$\text{R.Q.} = \frac{\text{CO}_2 \text{ excreted}}{\text{O}_2 \text{ absorbed}} = \frac{\dot{V}_{CO_2}}{\dot{V}_{O_2}} \simeq \frac{F_{A\,CO_2} - F_{I\,CO_2}}{F_{I_{O_2}} - F_{A\,O_2}}$$

The fractional concentrations in this equation can be converted to tensions (by multiplying each F by the barometric pressure (P_B) less 47 mm water vapour pressure at body temperature), the P_{CO_2} in inspired gas is negligible, thus:

$$R = \frac{P_{A_{CO_2}}}{P_{I_{O_2}} - P_{A_{O_2}}}, \text{ so } P_{A_{O_2}} = P_{I_{O_2}} - \frac{P_{A_{CO_2}}}{R}$$

Carbon dioxide, unlike oxygen, has an extremely high rate of diffusion, and there is virtually always equilibrium between alveolar and arterial carbon dioxide tensions. Riley and Cournand showed that if the arterial P_{CO_2} is used for $P_{A_{CO_2}}$ in this equation, then the "alveolar oxygen tension" calculated, knowing $P_{I_{O_2}}$ and the R.Q., was, even in abnormal subjects, very close to what the "ideal" alveolar oxygen tension would be if the subject had perfect balance of blood and gas flow. If the actual arterial oxygen tension is measured, then (1) the alveolar-arterial oxygen tension difference can be expressed and (2) the "venous admixture effect", in terms of what percentage of the cardiac output appears to be shunted through the lungs, can be calculated.

In a similar manner, relative overventilation of alveoli will reduce the proportion of carbon dioxide added to the expired gas. By relating the expired carbon dioxide to the arterial P_{CO_2} it is possible to extend the concept of physiological deadspace to give a measure of the amount of relative overventilation of some alveoli as if there were in the lung areas of alveolar ventilation, with absolute lack of perfusion, with the remainder of the lung having the "ideal" balance. This "deadspace effect" includes the anatomical deadspace together with the increased alveolar deadspace. It is usually expressed as a percentage of the tidal volume or total ventilation:

$$\text{Deadspace effect } (\%) = \frac{P_{A_{CO_2}} - P_{E_{CO_2}}}{P_{CO_2}} \times 100$$

In emphysema, the alveolar-arterial oxygen tension difference may be 50 mm Hg, whereas in normal subjects it is less than 10 mm breathing air at normal atmospheric pressures. The venous admixture effect (perfusion of underventilated alveoli) may be over 30 per cent of the cardiac output; in normal persons it is never more than 5 per cent. The deadspace effect (including ventilation of underperfused alveoli) may become as high as 60 per cent of the tidal volume, compared with the normal 30 per cent caused by the conducting passage. It is this increase of "alveolar deadspace" in the disease that leads to most of the increased ventilation for a given oxygen uptake.

The alternative method of revealing regional lack of balance between alveolar blood and gas flow, entails rapid continuous analysis of expired gas so as to determine the actual gas tensions coming from different groups of alveoli. With a suitable mass spectrometer this can be done and a measure of the degree of regional ventilation-perfusion inequality in normal or diseased sub-

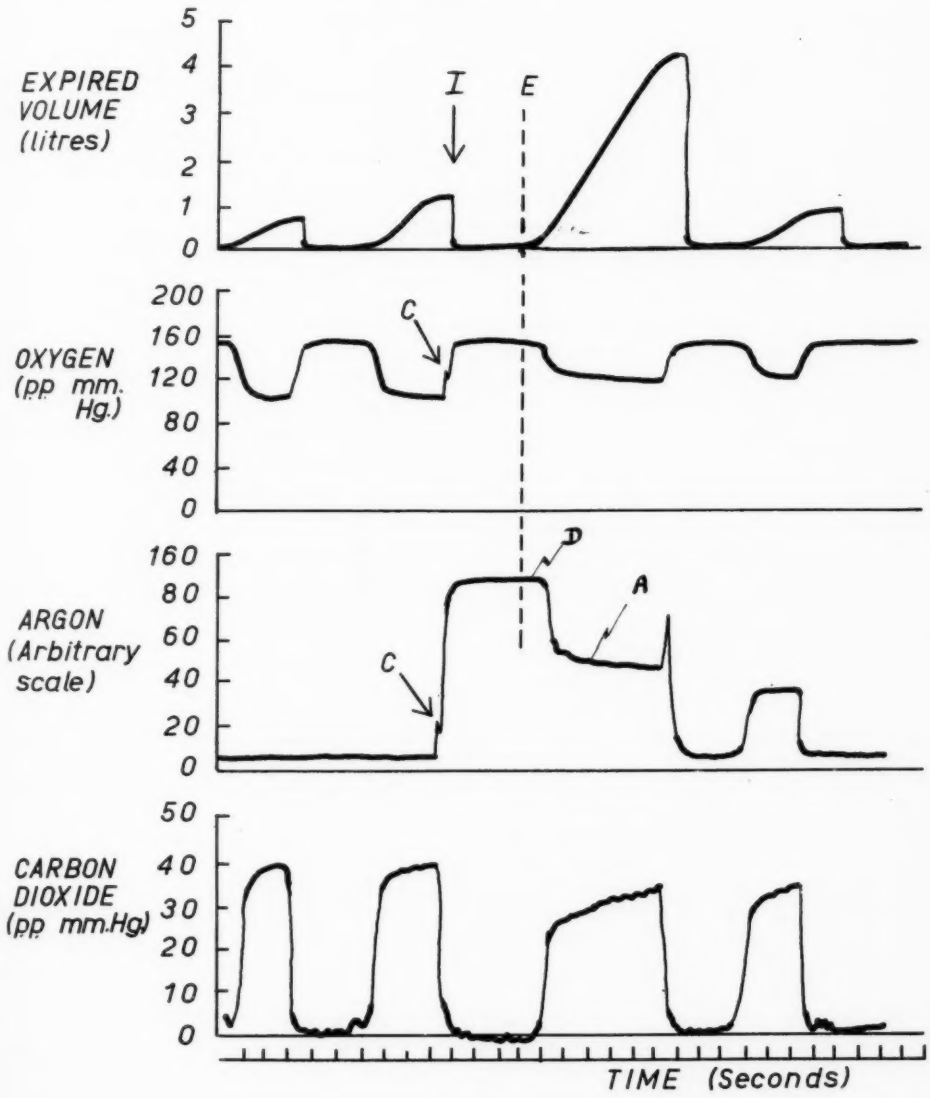


FIG. 8

Continuous rapid alveolar gas analysis using a suitable mass-spectrometer. The record, copied from the direct-writing recorder, shows concurrent analysis for three gases and includes a single long expiration (starting at E) after an inspiration (at I) of air blended with argon. From the argon trace any uneven gas distribution can be demonstrated; from the CO_2 and O_2, the change in alveolar RQ is obtained, from which the variation in ventilation-perfusion relationship can be calculated. (C) represents clearance of apparatus deadspace by the inspired argon-air blend; (D) gas from upper respiratory deadspace; (A) Alveolar plateau for argon. (For details see West et al., 1957.)

jects becomes a rapid lung-function test, simple enough for clinical use because it only entails a single expiration from the subject (West et al., 1957).

The principle is similar to that for measuring regional inequality of ventilation by a single breath test, described previously, except that the expiration is analyzed for the change in oxygen and carbon dioxide tension in relation to the volume of gas exhaled (fig. 8). This enables the respiratory quotient from different groups of well-ventilated alveoli, which empty early in expiration, to be compared with that from groups emptying late. The minimum inequality of ventilation-perfusion ratios in different parts of the lung, which are needed to account for the observed change in respiratory quotient, is then calculated. In emphysema there may be over 40 per cent change in ventilation-perfusion ratio observed by this method, compared with an upper limit of about 10 per cent in normal subjects.

Comments and Clinical Significance. Lack of balance of ventilation and perfusion, together with hypoventilation are the major factors which produce the gross abnormalities of arterial blood gas tensions ("lung failure") which are seen in severe emphysema and probably determine the onset of the subsequent heart failure. The relation between these two factors is complex, and the reader is referred to the discussion in Comroe et al. (1955), Chapter 4, but as it is of great practical importance to the anaesthetist and clinician in the management and treatment of emphysematous patients, some of the main points will be discussed here.

A raised ventilation-perfusion ratio, in an alveolus, can hardly increase the oxygen saturation of the blood leaving that alveolus (because it is already nearly fully saturated with the normal ratio), but it will lower the tension of carbon dioxide. A lowered ratio will reduce both the oxygen and carbon dioxide tensions. Thus, if different ventilation-perfusion ratios occur in a subject previously normal (for example, by a patchy bronchopneumonia causing reduced or absent ventilation in many groups of alveoli where the perfusion is still normal), there will initially be a fall in P_{O_2} but a rise in P_{CO_2} in the arterial blood. The respiratory centre is stimulated and there is an increase in the overall alveolar ventilation. This hyperventilation of alveoli which were unaffected will lower the arterial P_{CO_2} but does little to raise the arterial oxygen saturation. Hence the common response to pneumonia in an otherwise normal patient: cyanosis, increased ventilation but a normal arterial carbon dioxide tension. An emphysematous patient often does not increase his ventilation adequately or at all, to compensate for the raised carbon dioxide because of the mechanical disturbance in his lungs, so that hypoventilation is added. Thus he has a raised P_{CO_2} and a lowered P_{O_2}.

Hypoventilation, alone, with no ventilation-perfusion disbalance will lead both to carbon dioxide retention and a lowered P_{O_2}. But owing to the shape of the oxygen dissociation curve, when the P_{CO_2} is raised to about 60 mm Hg (and the P_{O_2} lowered to about 80 mm Hg with an R.Q. of 0.8) the oxygen saturation will be still about 92 per cent, and there is no cyanosis. Conversely, a disturbed ventilation-perfusion balance may lead to a fall of oxygen tension severe enough for cyanosis with little or no rise of P_{CO_2}, if compensatory increase in ventilation can take place. In emphysema, all combinations of ventilation-perfusion inequality and hypoventilation can be found, though in severe cases, especially with infection, both are usual, and cause severe "lung failure", a lowered arterial oxygen saturation, raised carbon dioxide tension, and the low pH and high serum bicarbonate of respiratory failure.

Finally, it must be realized that although regional underperfusion is *expressed* as a "venous admixture" effect, there is usually no absolute shunt. On breathing pure oxygen the arterial blood becomes fully saturated.

Diffusing Capacity.

Observations. Bates et al. (1956) measured the "diffusing capacity of the lung" using the carbon monoxide steady state method. They found a severe reduction of diffusing capacity in advanced emphysema. Since the diffusing capacity increases on exercise in normal subjects, a phenomenon thought to be caused by opening up of blood capillaries with an increase in the area available for gaseous diffusion, the diffusing capacity for carbon dioxide or D_{CO_2} is often recorded on exercise to find its maximum value. Bates et al. (1956) stress not only the falling off in diffusing capacity at rest with advancing emphysema but the relative failure to augment the diffusing capacity on exercise, in this condition.

The alternative technique of measuring the Dco by a single breath inhalation (Ogilvie et al. 1957) shows a less marked decline in diffusing capacity in emphysema, though in occasional severe cases at rest, it can be reduced from the normal of about 15 ml/min/mm Hg down to less than half that value.

Carbon monoxide is used to measure the diffusing capacity largely because of simplicity and the difficulty of measuring it for oxygen. With carbon monoxide the mean tension in the lung capillaries is assumed to be about zero (because of the enormous affinity of carbon monoxide for haemoglobin), so that if the average alveolar tension can be measured at the same time, the Dco can be calculated.

With oxygen the mean capillary tension is not negligible and is difficult to determine, and any alveolar underperfusion also affects the alveolar-mean-capillary gradient for oxygen. However, these difficulties can be partly overcome, though the technique is complex and entails studies of oxygen uptake and blood gas tensions both when the patient is breathing a high and a low oxygen mixture. By this technique (Donald et al., 1952), the D_{O_2} was found to be reduced in some cases of emphysema, the impairment being most pronounced in those who had also had the largest combined venous admixture and deadspace effects.

Comments. Recent work on the difference between the results obtained from the single and multiple breath carbon monoxide technique suggests that much of the abnormality revealed by the latter may be accounted for by regional inequality of gas distribution in the lungs. Neither the histology, nor other functional studies, suggest gross change in the barrier to oxygen uptake per unit of surface area in the lungs. The significance of measurements of diffusing capacity in emphysema is at present controversial, but it seems likely that there is an effective reduction of surface area available for diffusion mainly because of the disturbed ventilation-perfusion balance, but that this reduction in effective surface does not become pronounced in its effects in limiting total gas diffusion till the condition is advanced.

In other words, the disturbed lung mechanics and inability to ventilate set a limit to activity before that set by maximum oxygen uptake in most cases of emphysema.

SUMMARY OF THE FUNCTIONAL PATHOLOGY AND ITS CLINICAL SIGNIFICANCE

The nature of emphysema. We can now summarize the nature of the functional lesion in a patient with advanced emphysema. His chest is held in the inspiratory position (often, but not always with an increase in total lung volume) because of the loss of elastic recoil of the lungs and the marked tendency to trap air (airways collapse) if he attempts to use the musles of expiration to compensate for this loss of elasticity. Consequently, he has a grossly diminished ventilatory reserve for exercise, partly from a small vital capacity, but more because of the narrowed airways causing a greatly increased expiratory resistance to air flow. The inspired air is unevenly distributed in the lungs; worse, there is lack of balance between air and blood flow resulting in an increased ventilatory requirement for a given oxygen uptake (which usually cannot be provided because of the mechanical difficulties), and hence there is both oxygen desaturation and carbon dioxide retention in the arterial blood. In the latest stages of the disease a decreased diffusing capacity may be added to the gross lack of balance between gas and blood flow, and heart failure—secondary to the primary lung failure—supervenes.

These combined functional changes are characteristic of emphysema. Other conditions may be similar in some features. For example, patients in a severe attack of spasmodic asthma have their chests held high in inspiration, with the attendant increase in F.R.C., and have an equally diminished ventilatory reserve. But they rarely have such a lack of balance between ventilation and perfusion so that gross change in arterial blood gas tensions are rare. The latter only occur in status asthmaticus from pure hypoventilation, largely because of airways obstruction by secretion. Moreover, there is no loss of elasticity and the obstruction to airflow is of a different nature. Although it is greater in expiration than inspiration, the inspiratory obstruction is greater than in emphysema.

The problem of diagnosis may be very great, especially when emphysema is combined with bronchitis and asthma. The only reasonably cer-

tain method of making a positive diagnosis in life, is testing for the specific changes described, taking account of test results in relation to the clinical findings and history.

Relation of the functional lesion to progress. In spite of the gross and widespread functional abnormality in the advanced cases, which makes the emphysematous patient so difficult for the anaesthetist, the condition is often not quickly progressive and the amount of emphysema may go in infinite grades from nothing to the advanced stage, taking many years to develop. The rate of change seems to be related to the age of onset, again rather like diabetes, and definite emphysema in young subjects, while rare, is usually quickly progressive. Emphysema is common in the elderly, but then it is often only slowly progressive (Stuart-Harris and Hanley, 1957).

Some patients seem to have more of the purely mechanical ventilatory disturbance, some have more of the lack of balance between ventilation and perfusion, and have change in arterial blood gas tensions out of proportion to their ventilating defect. Some patients seem to "accept" breathlessness and maintain their arterial P_{CO_2} relatively normal by increasing their ventilation, while others seem to let their blood gas tensions become abnormal, hypoventilate and complain less of dyspnoea. However, the relation of function to different clinical and pathological types of emphysema and to the rate of progress of the condition is not yet worked out.

The onset of cor pulmonale possibly depends mainly on the degree of disturbance in blood gas tensions. There are three main reasons for believing this. There is evidence from animal and human experimental physiology that anoxia can produce acute increase in pulmonary vascular resistance and hence pulmonary hypertension. The onset of cor pulmonale and cyanosis (which means a markedly lowered P_{O_2}) tend to occur concurrently. Finally, returning the grossly abnormal blood tensions (during periods of hypoventilation following infection) to normal by mechanical artificial ventilation appears to lower the pulmonary artery pressure.

A bout of infection is the commonest cause of sudden deterioration in the functional state. The emphysematous patient does not increase his ventilation in response to bronchopneumonic increase in ventilation-perfusion inequality like other patients, probably because of the extreme stimulation of stretch receptors and chronic insensitivity of the respiratory centre to carbon dioxide. The patient consequently has carbon dioxide retention, respiratory acidosis and increased cyanosis and often a rise of pulmonary artery pressure and heart failure. Giving oxygen, which will relieve the anoxaemia, removes part of this respiratory drive resulting from anoxia, the ventilation falls further and the arterial P_{CO_2} rises, with consequent rise of cerebrospinal fluid pressure, and coma in extreme cases.

The functional lesion and treatment. There is no known curative treatment of emphysema itself, but appreciation of the functional changes enables the physician to slow or prevent the deterioration by removal of complications. The two main therapeutic measures are to improve the main functional defects—in overall ventilation and in the distribution of blood and gas. Nothing can be done to replace the loss of capillary bed and its contribution to loss of lung-diffusing capacity.

In the chronic state, treating superadded bronchitis and asthma is vitally important. Treatment of the former (by postural drainage, antibiotics, and omission of smoking) will keep air distribution as normal as possible. Treatment of the latter will remove what is often an entirely unnecessary added reduction in air flow and ventilatory capacity. Detection and treatment of bronchospasm complicating emphysema is urgent and important.

In acute exacerbation from respiratory infection, oxygen is needed to relieve the anoxaemia and help heart failure. It should be given freely, but this can only safely be done if any consequent hypoventilation is treated by frequent chemical stimulation of the respiratory centre (with nikethamide, aminophylline, or possibly amphetamine) or, in the few cases where this fails, by artificial mechanical ventilation using a cuffed tube as a temporary basis or tracheostomy for longer periods.

Effective increase in ventilation by intermittent positive pressure breathing in the conscious subject is difficult to achieve, and we have had rather less success with this measure than is claimed in some American work.

(A) (B)

FIG. 9

Radiographs: (A) Patient with extreme functional disturbance. Cyanosed, and bed-ridden by breathlessness, he died shortly after this photograph. (B) Patient with very good exercise tolerance ("could run for a bus") and lead a satisfactory life. (A) has emphysema and a gross lack of balance between ventilation and blood flow throughout the lungs. (B) has poor air flow to the left lung, from radiation fibrosis, but poor blood flow there as well.

Finally there is the place of surgery now and in the future. Removal of large bullae in emphysematous patients (or other patients for that matter) often improves the mechanics of the chest and helps to prevent air-trapping, though the choice of patients suitable for this treatment requires considerable skill. "Bullectomy" may also help in some cases by removing alveolar deadspace, though the significance of this effect is less certain. "Plexotomy" or, in a few cases, vagotomy alone may help by relief of dyspnoea, presumably by cutting the path of stretch receptors. Attempts have been made to remove the hypoventilation of advanced chronic emphysema (so as to improve arterial gas tensions and prevent pulmonary hypertension) by giving patients salicylates and other respiratory stimulants. In occasional cases this treatment meets with some success, but the patient may be rendered more breathless; possibly, if the stretch receptors could be cut, this treatment would be fruitful in halting the course towards cor pulmonale.

DIAGNOSIS AND ASSESSMENT BEFORE OPERATION

Most of the tests of lung function which have been mentioned are complex and only available at highly specialized centres. However, an understanding of functional lesions of the chest, from the results of these tests, greatly enhances clinical acumen and makes it possible to interpret history and physical signs so as to make a reasonably satisfactory functional diagnosis in many cases. But the chest radiograph, which is so much more helpful than physical signs, in the diagnosis of anatomical pathology (the recognition of lung cancer, tubercle, bronchiectasis, etc.) can be misleading in the diagnosis of function (fig. 9).

It is suggested that the anaesthetist, when he sees a patient with chronic respiratory disease before operation, should ask himself two sets of questions, concerned with an attempt at precise pathological and functional diagnosis, respectively:

A. Pathological diagnosis.

(1) Has the patient really got any emphysema, and if so of what degree?

(2) Has he chest infection?

(3) Does he get accompanying asthma?

B. Functional diagnosis.

(1) What is the ventilatory reserve of the lungs? If a thoracic operation is contemplated, what is it likely to be afterwards?

(2) Is the patient's resting ventilation adequate to maintain a normal arterial carbon dioxide tension or is he hypoventilating?

(3) Can the patient maintain a normal arterial oxygen saturation at rest or on exercise?

These questions may have to be attempted on clinical judgment only. Some of the answers may then be impossible to provide. A suggestion for the use of simple lung function tests is therefore given. In either case the significance of these questions in relation to anaesthesia and postponement of operation is discussed.

Clinical Assessment.

This is discussed in the clinical section of this symposium (Dornhorst, 1958). It is sufficient here to stress the importance of age and of a history of excessive breathlessness on exertion, without other apparent cause, in the diagnosis of emphysema. The breathlessness should be assessed in terms of simple clinical grades as suggested by Fletcher (1952). A history of the type and quantity of sputum for the diagnosis of bronchitis, and of using a leading question about wheezing (preferably with a demonstration!) for the diagnosis of accompanying asthma, is likewise stressed.

On examination, stress is laid on listening for asthmatic wheeze (often heard best by auscultation over the trachea) and of thinking in terms of the probable M.B.C. when looking at chest movement, testing for air-trapping (see clinical section), or considering a wheeze as evidence of air-flow obstruction. However, quantitative measurement of M.B.C. is far more satisfactory, and the simple measurement of F.E.V. is excellent for this purpose. An attempt can be made to get evidence of hypoventilation from the presence of vasodilation; and of exercise capacity, together with exercise desaturation, from watching the patient exercise (going upstairs). Again, however, simple quantitative tests are more satisfactory.

Simple Function Tests.

Of them all, the measurement of the one-second F.E.V. during a forced vital capacity test, using a spirographic record or automatic timing device, is the simplest and most informative for

our purpose. This test should be freely available. The M.B.C. can be determined from it. Repetition of the test after an inhalation, adrenalin and atropine compound (B.P.C.) or of isoprenaline, from a suitable hand-nebulizer, will help to detect asthma and make the diagnosis of emphysema most unlikely if the F.E.V. forms a percentage of the V.C. greater than about 70 per cent (Thomson and Hugh-Jones, 1958).

If hypoventilation is suspected, the presence of a raised serum bicarbonate should be looked for. This is not pathognomic without an arterial pH measurement because it can arise from a metabolic alkalosis rather than as a compensation for respiratory acidosis, though, in practice difficulty does not often arise.

These two tests should be available and their use, together with clinical appraisal, should deal with most problems. A standard exercise test using an ear oximeter is a useful adjunct to answer the last question suggested for functional diagnosis. But this is already getting beyond what is likely to be available. Unfortunately, many problems about the advisability of operation are highly complex in emphysematous patients, and are outside the scope of the anaesthetist himself. They demand close liason between physicians, surgeons and anaesthetists, with access to all the various tests of lung function, if they are to be answered on a rational basis.

Postponement of Operation.

The presence of chest infection, asthma, or poor exercise tolerance associated with obesity, may make it advisable to postpone operation on functional grounds. Emphysema itself can be so severe in rare instances, as to make anaesthesia and operation dangerous and call for abandonment; postponement is only indicated if one of these three accessory factors is also present to interfere further with a lung function of an emphysematous patient.

If the M.B.C. is very low (less than 30 or 40 l./min, depending on age and sex), and especially if hypoventilation is present, then every effort should be made to treat any of these three factors that may be present. It is well worth postponing operation in an emphysematous patient judged to be a "poor risk", to clear purulent sputum by antibiotics and postural drainage, to relieve bronchospasm by the frequent use of a hand-neubulizer (with a demonstration of how to use it!) together with long acting antispasmodic tablets (e.g. choline theophyllinate), or to give time for dietary weight reduction.

F.E.V. measurements, before and after an antispasmodic aerosol, are invaluable in assessing the benefit likely to be obtained from postponement of operation and, if repeated during treatment, in measuring the actual benefit obtained.

Abandonment of Operation.

This is outside the scope of the anaesthetist. In chest surgery itself, lobectomy rather than pneumonectomy, or total abandonment in favour of, for example, X-irradiation, might be advisable on grounds of inadequate ventilatory reserve after operation or of possible excessive exercise ventilation after operation. But the problem is highly complex, often demands full functional assessment and even then the decision must rest with the surgeon or physician, who is given the facts; this is especially so in the case of malignant disease.

Finally, if thoracic surgery is undertaken to treat emphysema (in the way of removal of bullae) it is well to remember that success is often most apparent in the most severely disabled subjects who appear to be exceedingly bad anaesthetic and operative risks. In such subjects a distended bullae may behave like a tension pneumothorax, and its removal give striking benefit; a radiographically similar bulla, in a patient without obvious symptoms, may be functionally unimportant and its removal may produce most adverse effects. Such decisions about operation do not rest with the anaesthetist. But he must use all his skill and knowledge of lung function if a severely disabled emphysematous subject is to undergo surgery.

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CLINICAL ASPECTS OF EMPHYSEMA

BY

A. C. DORNHORST

*Department of Medicine, St. Thomas's Hospital, London, S.E.*1

SYMPTOMS AND SIGNS

THERE is only one symptom proper to emphysema, namely progressive exertional dyspnoea. Cough and sputum, symptoms of associated bronchitis, often, but by no means always, accompany the dyspnoea. Eventually many patients develop cardiac failure and complain of weakness and of oedema; but this complication is outside our present scope and will not be further considered.

The signs of emphysema may be considered under two headings; those of impaired ventilatory mechanics, and those of impaired ventilatory utilization.

One of the most consistent of the former group is a shift of the relaxed posture of the chest towards inspiration, together with sharp limitation of expiratory reserve. Associated changes are reduction in chest expansion, early inspiratory recruitment of scalenes and sternomastoids, and inspiratory indrawing of the lateral part of the costal margins. The latter sign is caused by the horizontal pull of the flattened diaphragm, and may be distinguished from the retraction of the lower sternum that accompanies impeded breathing. Typically the breath sounds are quiet: the expiratory sound being often inaudible and the inspiratory having a characteristic subcrepitant quality which has been likened to the sound of skis in soft snow. As these signs are largely exaggerations of normal age changes, they are more significant in younger patients. Increased work cost of ventilation is commonly present and may be evidenced by apparent respiratory effort, by inspiratory retraction of the lower sternum and basal ribs, and by increased respiratory swing of the deep venous pulse in the neck. All the signs described are more difficult to evaluate in the presence of bronchitis.

Impaired ventilatory utilization is more difficult to recognize clinically. If it is sufficiently severe the patient will show, even at rest, either central cyanosis or hyperpnoea; but these signs are more easily recognized after moderate exertion.

Finger clubbing is not a feature of uncomplicated emphysema: its presence suggests either bronchiectasis or one of the poorly understood diffuse granulomatous conditions of the lungs.

RADIOLOGY

The radiological appearances seldom play much part in establishing a diagnosis of significant emphysema. It is true that in most cases the radiograph shows some changes, but the correlation with disability is quite poor. Some patients with well developed emphysema have substantially normal radiographs, while striking appearances, due to localized bullae, may be without clinical significance.

The most consistent radiological features of generalized emphysema are an exaggerated inspiratory posture with flattened diaphragm, and a paucity of vascular markings in the peripheral lung fields. The usefulness of these signs is lessened by the sensitivity of the former to variations in the patient's pre-exposure inspiratory effort, and of the latter to variations in exposure parameters. Enlargement of the pulmonary artery trunk and main branches occurs as pulmonary hypertension develops, and this greatly strengthens the radiological diagnosis. Cardiac enlargement remains inconspicuous in the posterio-anterior film until the onset of anoxic heart failure.

Reduced diaphragmatic movement is frequently noted in inspiratory-expiratory films, but this merely duplicates the clinical finding of reduced vital capacity.

Evidence of local bullous change supports but

does not establish the diagnosis of generalized emphysema. Such local changes may sometimes be demonstrated by bronchography or tomography when the straight film is inconclusive.

DIAGNOSIS

The clinical picture in emphysema varies not only in overall severity but also with the relative importance of the two main component disturbances, namely mechanical difficulty in ventilation and ineffectiveness of ventilation in allowing gas exchange. Some patients exhibit in addition evidence of reduced respiratory central drive. When emphysema is well developed and the component disturbances balanced, little difficulty in diagnosis should arise, but, when one or other factor predominates, the range of resultant pictures requires the differentiation of a variety of conditions.

Patients with predominant hyperpnoea are sometimes considered to be hysterical, especially if they are free from bronchitis. On the other hand the hyperpnoea of metabolic acidosis in renal failure is occasionally mistaken for that of emphysema. Emphysema with much laboured breathing has to be distinguished from left ventricular failure, particularly that due to ischaemic disease, from chronic asthma, and from pulmonary fibrosis.

When dyspnoea is due to heart disease examination will often reveal evidence of a cardiac lesion, or other evidence of cardiac failure. Failing that, help may be had from a radiograph since the peripheral pulmonary markings are usually heavy in cardiac dyspnoea.

Asthmatic patients seldom develop emphysema, so that a clear history of spasmodic attacks is evidence against the diagnosis; but chronic nonspasmodic asthma presents a more difficult problem. In asthma, the posture and movement of the chest, and its radiographic appearances, resemble those of emphysema. A useful point of differentiation is that the asthmatic patient's expiratory reserve is usually much larger than that of an emphysematous patient with similar functional residual volume. This is demonstrated by placing one's hands on the patient's chest and pressing while he makes a prolonged expiratory effort. The asthmatic chest will often deflate, though slowly, to a surprising extent. In emphysema, expiration often ceases after a few hundred millilitres with an abruptness that is felt almost as a jerk: a faint wheeze may persist, unaccompanied by further appreciable movement.

Diffuse pulmonary fibrosis tends to decrease rather than increase the functional residual volume. Sternal and basal retraction is conspicuous, and, in contrast to that occurring in emphysema, it persists during a maintained inspiration.

Emphysema presenting as cyanosis without respiratory urgency has to be distinguished from primary central respiratory depression, from veno-arterial shunts, and from met- and sulphhaemoglobinaemia.

Primary central depression is a rare condition whose existence has only recently been established. It may be suspected when a cyanosed patient appears to be underventilating in spite of considerable inspiratory and expiratory reserves, and is able to improve his colour by a voluntary increase in ventilation. The reported cases have either been grossly obese or have had some other evidence of cerebral disease.

Cyanosis due to congenital heart disease is unlikely to be confused with emphysema, but that due to pulmonary arteriovenous anastomosis can be baffling. The cyanosis is not relieved by hyperpnoea, and is little affected by oxygen breathing. There is, of course, no reason why the lung mechanics should be impaired.

Met- or sulph-haemoglobinaemia in a bronchitic or asthmatic subject can closely mimic emphysema. The commonest cause of methaemoglobinaemia is now the phenacetin in analgesic tablets, but a number of other drugs may be to blame. The fact that the cyanosis is due to an abnormal pigment is easily demonstrated by placing a drop of normal blood on a filter paper next to a drop of the patient's blood. The drops become oxygenated as they spread out, and the brownish discoloration caused by the abnormal pigment is easily recognized. This simple test is more sensitive than many of the hand spectroscopes used in clinical laboratories.

In spite of the variable clinical picture, the diagnosis of moderately advanced emphysema can usually be made on clinical grounds. In some cases uncertainty will remain, and the final opinion will depend on the results of physiological tests as described by Hugh-Jones (1958).

ASSESSMENT

Clinical assessment is based more on a detailed history of disability than on the nature of the physical signs. Even when the general level of disability has been small, the past occurrence of episodes of acute respiratory insufficiency—as might be provoked by acute bronchitis—gives a clear warning of what to expect if an operation should be undertaken.

Acute respiratory insufficiency may be provoked in an emphysematous subject by anything that further impairs any of the main divisions of respiratory function, namely, respiratory drive and muscle power, ventilatory mechanics and ventilatory utilization. Once the process has been started a vicious circle is easily set up. Thus sedation with morphine, methadone or barbiturates may depress respiratory drive to an extent of no consequence in a normal subject, but enough seriously to reduce ventilation in the face of mechanical difficulty. The resulting anoxaemia and hypercapnia may reach a degree that prevents normal recovery of the respiratory centre from the drug; meanwhile accumulating bronchial secretion further impairs mechanical function.

Similar events may follow acute bronchial infection or impairment of respiratory movement by thoracic or abdominal trauma—including that due to operations. An acute crisis may also be initiated by haemorrhage, a drop in the flow of haemoglobin through the lungs exacerbating the effects of anoxaemia.

TREATMENT

Treatment of the basal state is essentially directed against airway obstruction by attacking any bronchial infection or broncho-constriction that may be present. Because of their low peak airflows, emphysematous patients tend to be inefficient coughers, and their bronchial clearance may often be assisted by posture. However, common sense must be used, as they frequently tolerate badly any lengthy period with the head down, and they may have to be protected from physiotherapeutic zeal.

Purulent sputum is an indication for giving antibiotics, tetracycline being the most generally useful. The aim of the treatment is to convert the sputum from purulent to mucoid, and, if this has not happened in four days, another antibiotic should be substituted. In this way the risk of troublesome infection with resistant organisms will be avoided. Usually, the conversion of the sputum is accompanied by clinical improvement: very occasionally the mucoid sputum will be so tenacious that the last state is worse than the first.

In all patients the effect of an isoprenaline spray should be observed, preferably with some objective measurement to check the clinical impression. For this it is essential that the attendant should himself administer the spray; and if an effect is demonstrated the patient needs to be carefully instructed in its use. If isoprenaline is without effect, no benefit is to be expected from ephedrine, aminophylline or any other antispasmodics. If there is wheezing unrelieved by isoprenaline, the effects of corticoids should be tried. It is unwise to exceed a dose of 10 mg prednisone b.d. (or 50 mg cortisone b.d.) for continued treatment. The number of patients thus helped is rather small, certainly less than in chronic asthma.

There is no evidence that breathing exercises benefit emphysema.

Whatever the initiating cause, an episode of acute respiratory insufficiency is characterized by underventilation, anoxaemia and hypercapnia, and acute right ventricular overload. Treatment with antibiotics and isoprenaline is required, and in addition retained secretion may necessitate bronchial suction. As this may have to be frequently repeated, the situation is best met by a tracheotomy, which may be independently indicated by the need for mechanically assisted ventilation as described below.

Treatment should also be directed against the abnormal blood gas tensions. Anoxaemia is usually easily corrected by efficient administration of oxygen, either in a tent or by a plastic mask, rebreathing being avoided by a high flow. This treatment does not mitigate the hypercapnia and acidosis, and indeed often aggravates them; but, in spite of this, the patient is often so much improved by oxygen that it is clear no further action is needed. Increasing acidosis causes drowsiness and eventually coma, occasionally with convulsions. Although cerebral damage may be thus caused it must be stressed that anoxia is the greater threat, and oxygen therapy should certainly not be discontinued because of mere drowsiness. The onset of coma may be averted

by repeated injections of a respiratory stimulant such as nikethamide, but the effects are short lasting, and restlessness, twitching, vomiting, and sometimes convulsions may be produced.

If adequate ventilation cannot be maintained by these measures artificial respiration via a tracheotomy tube should be undertaken. This procedure may prove lifesaving, but a clear grasp of the factors involved, and suitable apparatus are essential for success. Tank respirators are unsuitable for this task.

To avoid serious loss of inflating pressure, the largest possible tracheotomy tube must be used. A respirator delivering a set volume, and capable of applying a negative pressure is desirable. Most efficient ventilation is achieved with a large volume and as slow a rate as the patient will tolerate. Ventilation should be sufficient to keep the patient without cyanosis: there is little danger of overventilation, but further control is provided by estimation of the plasma bicarbonate.

The reputation of this technique is likely to suffer from its employment without suitable indications, and because of the use of inadequate respirators.

Tracheotomy may be necessary in acute respiratory insufficiency for two reasons, which are distinct though they may co-exist. First, to avoid increasing obstruction by secretions in the absence of an efficient cough. Secondly, to allow artificial respiration when hypoventilation is due to a combination of mechanical difficulty and decreased respiratory drive. Treatment of bronchiolar obstruction with normal drive, as in severe asthma, should not be attempted by this means. Such patients are probably maintaining ventilation with an intrathoracic pressure swing of 40–45 cm H_2O, whereas most respirators are valved to limit at 25–30 cm H_2O. Thus unless the safety valves have been modified, artificial respiration will probably result in a disastrous drop in ventilation.

PROPHYLAXIS

The prevention of acute respiratory insufficiency is the problem for the anaesthetist when an emphysematous patient requires operation. Prophylactic postural drainage and antibiotics, and postoperative oxygen may reasonably be employed. The patient must not be allowed to become anaemic. It is important to avoid the pre- or postoperative use of respiratory depressive drugs. Possible alternatives are discussed by Nunn (1958).

Where an operation such as thoracotomy, which will inevitably impair ventilation, has to be performed on an emphysematous patient, it may well be that preliminary tracheotomy and planned postoperative artificial ventilation offers the best chance, but experience with this technique is so far lacking.

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THE ANAESTHETIST AND THE EMPHYSEMATOUS PATIENT

BY

J. F. NUNN

Research Department of Anaesthetics, Royal College of Surgeons of England

IT is surprising how few anaesthetists have ventured to publish their observations on the management of emphysematous patients. These patients are commonplace on operating lists but are notoriously difficult to anaesthetize. The anaesthetist is mainly concerned with emphysematous patients in four situations:

(1) Anaesthesia for extra-thoracic operations.
(2) Thoracic surgery which may result in a further reduction of pulmonary function.
(3) Thoracic surgery intended to improve pulmonary function.
(4) Artificial ventilation in the treatment of carbon dioxide narcosis.

ANAESTHESIA FOR EXTRA-THORACIC OPERATIONS

The problems.

In this country the anaesthetist usually encounters emphysema as a complication of chronic bronchitis. In addition to the problems of chronic infection, such patients present difficulties due to disordered pulmonary function and an altered response to drugs. Further complications arise from the sequelae of chronic respiratory inadequacy such as cor pulmonale, cerebral hypoxia and raised C.S.F. pressure.

It is well known to the anaesthetist that patients with chronic bronchitis have unusually sensitive respiratory tracts. Ether inductions are prone to be interrupted by periods of breath holding and coughing, and mechanical irritation of the trachea —particularly intubation or inflation of the lungs —may result in bronchospasm. Anaesthesia is frequently followed by an exacerbation of bronchitis leading to bronchopneumonia, which may have fatal consequences in the patient whose reserve of pulmonary function is already reduced.

Various aspects of the disordered pulmonary physiology of the emphysematous patient become evident to the anaesthetist. Apart from bronchospasm there may be considerable resistance to the flow of gases in the respiratory tract. The small bronchi may be structurally narrowed, but the highest resistance is encountered during expiration from airway closure. A spirogram of a forced expiration in a conscious emphysematous subject will reveal a reduced flow rate and in addition the expiration is arrested at a higher lung volume than the patient's customary functional residual capacity (F.R.C.); this is due to air trapping. The level at which trapping occurs is related to the gas flow rate during expiration. During the early part of a normal expiration, the gas flow is restrained by a gradual "let-down" of the tone of the inspiratory muscles. During intermittent positive pressure ventilation of the paralyzed subject, however, the airway pressure is often suddenly reduced at the end of inspiration, and the expiratory flow rate therefore tends to be maximal at the commencement of expiration. Thus trapping will be very likely to occur and the patient's expiratory level will rise above the F.R.C. More vigorous attempts at inflation will merely raise the expiratory level further and a number of anaesthetists have reported that emphysematous patients have become hyperinflated during artificial ventilation (Johnstone, 1956; Jacques, 1957).

The rate of uptake of anaesthetic gas is reduced by the large F.R.C. and by the impaired distribution of inspired gas. This is of minor importance with agents which exert their effect at relatively low concentrations in the blood—such as halothane and cyclopropane. With ether, however, a much higher concentration is required to produce anaesthesia and the time taken for induction is considerably prolonged. Postoperatively a longer time will be required for elimination. Nitrous oxide occupies an intermediate position as regards solubility in blood. Even in severe emphysema the time required to reach a narcotic

concentration in the blood will be sufficiently short for the modern techniques of supplemented nitrous oxide anaesthesia for major surgery. During anaesthesia for short outpatient surgery, however, it is doubtful whether an adequate blood level would be reached in the time usually allowed for induction under such circumstances.

Many of the difficulties of the anaesthetist are related to the reduced response of the emphysematous patient to high alveolar concentrations of carbon dioxide (Scott, 1920). Much of the apparent tolerance is due to mechanical inability to respond. It is known that hypoxia plays an active part in the stimulation of respiration in these patients and saturation with oxygen will markedly reduce the ventilation in patients with severe emphysema (Donald, 1949). Many anaesthetists habitually use high concentrations of inhaled oxygen during anaesthesia and this practice will not only reduce the spontaneous ventilation of emphysematous patients, but will, to a large extent, mask the hypoventilation by preventing the appearance of cyanosis. The situation is analogous to the treatment of emphysematous patients in oxygen tents and dangerous carbon dioxide retention can occur without warning. If, on the other hand, the inspired gas mixture contains only 20 per cent oxygen, the patient with severe emphysema will probably be cyanosed during anaesthesia with unassisted spontaneous respiration. The anaesthetist may thus be confronted with the choice between a pink underventilated patient who is retaining carbon dioxide and a cyanosed patient with a reasonable minute volume. It is perhaps hardly necessary to say that the addition of carbon dioxide to the inhaled gas mixture is unlikely to increase the ventilation.

The emphysematous patient may differ from the normal subject in his response to drugs. In particular there may be considerable respiratory depression following opiates and barbiturates. The muscular pattern of inspiration is abnormal in emphysema and a partial myoneural block may result in a disproportionate reduction in ventilation. The use of relaxants is further complicated by the hazard of neostigmine increasing bronchomotor tone, which may be of critical importance during anaesthesia complicated by bronchospasm.

Cor pulmonale is a complication from which the patient may ultimately die. It is therefore important not to subject the right ventricle to an unnecessary strain, such as might arise from increased pulmonary vascular resistance during severe hypoxia or some forms of artificial ventilation. If the brain has been exposed to chronic hypoxia, it is probable that it will be less able to withstand an additional acute episode of hypoxia.

Assessment.

In this symposium Hugh-Jones (1958) and Dornhorst (1958) have discussed the assessment of the patient. For routine surgery, the anaesthetist often sees the patient only the night before operation when it is unusual to have available more than the history, physical examination and perhaps a chest X-ray. Fortunately the history yields some of the most valuable information.

The anaesthetist must first decide whether the risks of anaesthesia are justifiable and for this he must consider both the medical and surgical condition of the patient. Secondly, he must consider whether any advantage would be gained by postponing operation. Many patients in surgical wards may not have had effective medical treatment in the past, particularly if their condition has deteriorated while on the waiting list. It is not possible to improve all aspects of the emphysematous process, but it is wise to treat infection and bronchospasm. In patients with advanced emphysema it may be advisable to postpone operation until the warmer weather. The third problem for the anaesthetist is the choice of the anaesthetic technique and the drugs which should be used.

Management.

Most anaesthetists find the management of emphysematous patients difficult and there are a number of different schools of thought concerning how best they may be anaesthetized. Probably no method will be suitable for all patients and each should be independently reviewed.

Regional and local analgesia offer the advantage of minimal interference with the disordered physiology of the patient, and spinal analgesia was once popular for emphysematous patients, being particularly suitable for genito-urinary units where so many emphysematous patients are encountered. Recently, however, the neurological sequelae of spinal analgesia have greatly reduced the popularity of the technique in this country although epidural block may be a suitable alternative.

Unfortunately emphysematous patients are not always able to co-operate fully, particularly if their position on the table hampers respiration. A laparotomy under regional analgesia is at best an ordeal, but it will be far worse should the patient normally rely upon the assistance of his abdominal muscles during expiration. The role of the abdominal muscles is, however, open to considerable doubt (Campbell, 1958). Heavy sedation is dangerous in these patients as it may easily cause respiratory depression, possibly followed by a vicious circle of carbon dioxide retention. Nevertheless, for certain operative sites—particularly the upper limbs—regional techniques are very suitable.

In spite of the hazards of rendering emphysematous patients unconscious, surgery is usually carried out under general anaesthesia. Premedication is the first and not the easiest problem to be faced. Heavy sedation with opiates or barbiturates may be dangerous; pethidine is, however, a suitable alternative. Hyoscine may cause disorientation in the elderly and atropine should be substituted. Promethazine is a valuable drug combining sedation, antihistamine action and some anticholinergic effect.

If the patient is to be rendered unconscious the next decision is whether to permit spontaneous respiration or to use artificial ventilation. There are those who employ assisted respiration, or possibly augmentation of alternate breaths, but these techniques are difficult and have not found widespread acceptance. The proponents of spontaneous respiration can put forward a number of advantages for their method. The respiratory response of the patient to the inhaled gas mixture is under continuous review and some of the difficulties in the re-establishment of spontaneous respiration after artificial ventilation are thereby avoided. Auld (1956) described an emphysematous patient who, after a period of artificial ventilation, would not resume respiration until he became mildly hypoxic and thus restored the "anoxic drive" on which his respiration normally depended.

The author has generally found more difficulty in restoring the carbon dioxide tension to a satisfactory level. Spontaneous respiration is unlikely to commence if the arterial carbon dioxide tension is more than about 10 mm Hg below the tension to which they are accustomed, and in emphysematous patients that tension may closely approach the level at which respiration is depressed by the narcotic action of carbon dioxide. The anaesthetist may thus be reduced to raising and lowering the carbon dioxide tension alternately in the hope of striking a level which is compatible with spontaneous respiration. Those who are not practising anaesthetists may well criticize the empirical nature of this procedure, but it is virtually impossible to make a precise estimate of the patient's carbon dioxide tension after two or three hours of artificial ventilation. Analysis of the arterial blood is seldom practicable and unfortunately the alveolar gas of patients with severe emphysema is not sufficiently uniform in composition to warrant determination of its carbon dioxide composition. As it is rare for there to be any biochemical evidence of the cause of the apnoea in these circumstances, it is probable that many problems of this nature are dismissed as an abnormal response to relaxant drugs.

The second problem of artificial ventilation is mechanical. During inflation high pressures may be required to overcome the airway resistance, although still greater resistance is usually encountered during expiration. Trapping and diminished elastic recoil leading to progressive overinflation have already been mentioned. Fortunately it is uncommon to meet this complication which may reveal itself by a greatly reduced ventilation (Jacques, 1957) or by a displacement of the diaphragm into the abdomen (Johnstone, 1956). With an intact thoracic cage, hyperinflation will raise the intrathoracic pressure to a high level and it may not be possible to compensate for obstruction of the venous return by elevation of the peripheral venous pressure. The patient is thus simultaneously faced with respiratory and circulatory failure. Johnstone (1956) describes dramatic relief brought about by manual compression of the upper abdomen and chest while Jacques (1957) brought equally dramatic relief to her patient by the employment of a subatmospheric airway pressure during expiration.

Apart from assisting expiration and improving the venous return, a "negative" pressure phase may prevent excessive right ventricular strain, which is important if the patient has pulmonary hypertension. However, a sudden drop of airway

pressure produces conditions similar to those during a forced expiration and may give rise to trapping—reducing rather than increasing the expiratory tidal volume. It is therefore advisable to reduce the expiratory airway pressure gradually while noting carefully any change in the tidal volume. The pressure could then be set a little higher than the pressure which resulted in the largest expiration. A pressure of the order of 5 cm water below atmospheric would probably be safe and should be applied gradually in the latter part of expiration. Siebecker and Curtis (1957) have described artificial ventilation in twelve emphysematous patients in whom they employed pressures 12 cm of water below atmospheric during expiration. They were able to maintain the mean arterial carbon dioxide tension at 45.5 mm Hg.

The third objection to artificial ventilation is the occasional development of severe bronchospasm following intubation and inflation. This complication is not confined to artificial ventilation and there have been cases when spasm following intubation has presented an immediate threat to life. It has been shown by Campbell et al. (1958) that artificial ventilation of the normal subject causes some imbalance of ventilation-perfusion relationships compared with spontaneous respiration while conscious. The emphysematous patient, however, already has defective relative distribution of blood and gas. Whether artificial ventilation accentuates the existing imbalance is not known but there have been suggestions that it may actually cause an improvement.

There remains the difficult question of the possibility of alveolar rupture during artificial ventilation. Gas has been known to penetrate the alveolar wall and either enter the pulmonary blood vessels or dissect back along the perivascular sheaths to the hilum. Having reached the mediastinum, gas may enter the pleural cavity or track along various planes of the connective tissue (Marcotte et al., 1940; Whittenberger, 1955). Similar complications may follow the retention of gas in the lungs during escape from submarines by free ascent (Woolmer, 1958).

The danger of rupture is related, not to the absolute alveolar pressure, but to the gradient across the walls of the alveolus (transmural pressure). In his classical experiments on alveolar rupture, Macklin (1937) inflated only one lobe or a part of one lobe, so that it was possible for the transmural pressure of the inflated alveoli to approximate to the inflation pressure. This would not normally apply during inflation of the whole of both lungs, since the intrapleural pressure would follow the alveolar pressure—differing only by the elastic pressure of the lungs.

In the emphysematous patient, however, local differences in airway pressure affect the distribution of inspired gas according to the rate of inflation. Thus some alveoli might rapidly attain the airway pressure while adjacent alveoli were temporarily protected by the resistance offered by their ducts (Pask, 1958). In this manner it would be possible to develop considerable transmural pressure in parts of the lungs, particularly if high inflation pressures were required to overcome the airway resistance as a whole.

In summary, it may be said that artificial ventilation usually guarantees adequate gaseous exchange for the duration of the anaesthetic and many anaesthetists regard this as more important than the objections listed above. However, if little or no relaxation is required, spontaneous respiration will usually be satisfactory if moderate desaturation of the arterial blood is accepted. The addition of oxygen to the inspired mixture must be cautious, as respiratory depression is easily produced and may be masked.

Although spontaneous respiration may be satisfactory for operations which do not require relaxation, it is considerably more difficult to manage during laparotomy. Even in the normal patient relaxation suitable for abdominal surgery is frequently associated with a reduced ventilation and, in an emphysematous patient with disordered mechanics of breathing, there may be severe hypoventilation. It would appear that accessory muscles which are important to the emphysematous patient—such as the sternomastoids—do not contract effectively during deep anaesthesia. Thus, for laparotomy, there is a particularly strong case for the use of artificial ventilation as a routine for patients with severe emphysema. If it is intended to retain spontaneous respiration, the more powerful inhalational agents are easier to use than a combination of the relaxants and supplemented nitrous oxide. Ether is generally satisfactory once anaesthesia is established, but, for the reasons

given above, induction may not be easy. Much of the difficulty of the induction may be avoided by intubating the patient after thiopentone and suxamethonium, and subsequently building up the blood ether level during artificial ventilation before spontaneous respiration returns. Ether is an effective bronchodilator but this effect may be offset by increased secretion of mucus. Cyclopropane causes dangerous degrees of respiratory depression and certainly should not be administered with the customary high concentration of oxygen. It is possible that halothane will prove to be a satisfactory agent for emphysematous patients.

The choice between spontaneous and artificial ventilation rests not so much on the rival merits of the two methods, but rather on which has the fewer difficulties and dangers. It is impossible to be dogmatic on which technique is most suitable for all patients and the anaesthetist should be guided by the patient, the operation and also by his own experience and competence with the two techniques. It must be stressed that oxygenation is vastly more important than any other factor to do with respiration. This is particularly true in emphysematous patients in whom hypoxia will tend to cause pulmonary hypertension which may precipitate right ventricular failure.

Special mention must be made of bronchoscopy to which many emphysematous patients come for the exclusion of bronchial carcinoma. Anaesthesia for bronchoscopy is difficult, even in the normal subject, as it is not easy to maintain both oxygenation and relaxation while the bronchoscope is in place.

In the emphysematous patient there is little doubt that topical anaesthesia should be the method of choice. If general anaesthesia is necessary, curarization will usually be required to control the cough reflex, and steps must then be taken to maintain oxygenation during apnoea. Preliminary inhalation of oxygen is valuable and oxygen may be insufflated down the side of the bronchoscope, although diffusion will not be wholly satisfactory. There is little danger of carbon dioxide retention in such a short procedure. A cuirass respirator used in conjunction with a short-acting relaxant is probably the safest form of general anaesthesia for this combination of a difficult procedure and a difficult patient.

THORACIC SURGERY WHICH FURTHER IMPAIRS PULMONARY FUNCTION

Great care is needed in the selection and management of emphysematous patients for surgery which will result in a further reduction of pulmonary function. This problem is most frequently encountered with pneumonectomy and to a lesser extent with lobectomy and segmental resection. Carcinoma of the lung is the principal disease in which this problem arises, as it tends to occur in the same type of patient who is likely to develop emphysema. Carcinoma of the oesophagus may also co-exist with emphysema, but the problem is simpler, as oesophageal resection is only followed by the temporary impairment of respiratory function associated with anaesthesia and thoracotomy.

Thoracotomy without resection of pulmonary tissue is followed by a period of hypoventilation, the duration of which is being investigated at a number of centres. It is unusual for the alveolar carbon dioxide tension to return to the pre-operative level for one or two hours and this time may well be considerably prolonged. The cause is probably a combination of residual narcosis and myoneural block together with the considerable pain of breathing associated with the incision. Possibly bandages or strapping may also reduce ventilation.

Inadequate ventilation after thoracotomy is most frequently seen after pneumonectomy when the diseased lung has made an appreciable contribution to function, and the remaining lung has severe emphysema. The condition becomes apparent immediately after operation when the patient is seen to be unable to maintain oxygenation while breathing air. It is not unusual for patients to regain consciousness and then hypoventilate and relapse into coma when the arterial carbon dioxide tension reaches a level of the order of 120 mm Hg (Westlake et al., 1955). They may then be re-intubated with ease and hyperventilated artificially. After a few minutes they regain consciousness, often remove the endotracheal tube themselves and vigorously resent any further attempts at ventilation. The cycle then recommences and again they lapse into hypoventilation and carbon dioxide retention from which they may be again retrieved by hyperventilation when their plane of consciousness is sufficiently deep to tolerate an endotracheal tube.

The first steps should be taken to treat the causes of respiratory failure which are associated with the anaesthetic and are therefore temporary. Attention should be paid to residual curarization and to central depression from barbiturates or opiates which have been exhibited over the previous two or three hours. The dressing and position in bed should be examined and the pressure in the pleural cavity should be measured to exclude tension pneumothorax, since rupture of bullae may easily occur at thoracotomy. The presence of a drain will not necessarily rule out this possibility as drains can easily become blocked or kinked in the immediate postoperative period.

Chemical stimulation is worthy of trial. Bemegride or amiphenazole are the most suitable agents but the patient must be carefully watched and the drugs repeated as necessary. On occasion niketha-mide will lighten the level of consciousness to the stage at which it is possible to obtain the co-operation of the patient and to exhort him to ventilate more vigorously. If, in spite of these measures, the patient is unable to accomplish satisfactory gas exchange, it will be necessary to ventilate him artificially until the temporary hindrances to respiration have subsided (Björk and Engström, 1955). This may take a few hours or a few days and, on rare occasions, it may eventually become apparent that the patient has become a permanent respiratory cripple.

After a thoracotomy it is seldom possible to carry out efficient artificial ventilation for any length of time without a tracheostomy. Not only is it essential for intermittent positive pressure respiration (which is the best method), but it is also valuable for clearing secretions. The reduction in deadspace amounts to about 70 ml and sometimes tracheostomy alone is sufficient to prevent the patient developing carbon dioxide retention. Certainly a tracheostomy will enable a patient to resume spontaneous respiration at the earliest possible time after artificial ventilation. Tracheostomies heal so quickly that some units perform them routinely if there is a likelihood of an emphysematous patient having respiratory inadequacy or troublesome secretions after pulmonary resection. It should be remembered that the efficiency of a cough is already reduced in emphysema and still further reduced in the postoperative period.

A mechanical ventilator is probably superior to manual ventilation in the treatment of carbon dioxide retention postoperatively because the ventilation is apt to be interrupted by periods of hypoventilation when an assessment of the patient's ability to breathe is made. It is more satisfactory to maintain artificial ventilation until the patient is fully conscious. Certainly little harm and even some good may be achieved by continuing artificial ventilation longer than it is required.

Postoperative carbon dioxide retention may not develop until after the patient has returned to the ward. Recognition of the condition is important and the nursing staff should be warned of the possible dangers of oxygen therapy which may precipitate and also mask hypoventilation. A rising blood pressure is not invariably seen in carbon dioxide retention, but if the blood pressure after operation rises progressively above the pre-operative level it is sufficient evidence—particularly if it is associated with deepening of the plane of consciousness. A half-hourly blood pressure record is a valuable precaution and it is essential that all concerned should be aware of the significance of a rising pressure. Sweating associated with a flushed appearance is also suggestive of carbon dioxide retention and an irregular pulse has also been noticed at a late stage shortly before death. Postmortem examination reveals no pathognomonic features and the cause of death can seldom be established unless diagnosed during life.

Prediction of the ability of a patient to ventilate after pneumonectomy is difficult. Contralateral disease is of great importance and emphysema is probably the commonest cause of disability in this respect. Not only must the maximum breathing capacity be assessed but also what part of the total function is carried out by the lung which will be removed. Bronchospirometry would appear to be the most satisfactory method, but practical difficulties have retarded its use. Screening is often of value but considerable experience is required to relate the appearances to function. The respiratory quotients of gas expired from the two main bronchi will also indicate the relative function of the two lungs. Samples may be collected during bronchoscopy (Armitage and Taylor, 1956). The overall function should only be considered in relation to the differential function of the two sides,

but it is generally agreed that a maximum breathing capacity in an adult of 35 litres per minute or less should be regarded as a contra-indication to operative interference (Donald, 1953).

It is perhaps outside the scope of the anaesthetist to consider the rise in pulmonary artery pressure which may follow pneumonectomy in the emphysematous patient. During cardiac catheterization it is possible to occlude the pulmonary artery of the diseased side and so to predict the rise in pressure which may be expected to follow pneumonectomy (Hanson, 1954; Nemir et al., 1956). In this way it may be possible to avoid surgery in those patients in whom resection might be followed by right ventricular failure.

After pneumonectomy the remaining lung expands and this condition is known as compensatory emphysema. There is some doubt as to whether it constitutes distension or true emphysema. Certainly if the remaining lung is already emphysematous the distension will be harmful and this factor must be considered in the preoperative assessment. Thoracoplasty may be employed to prevent overdistension of the remaining lung but its use is not widespread in this country.

THORACIC SURGERY INTENDED TO IMPROVE PULMONARY FUNCTION

Denervation.

Patients who have considerable relief from bronchodilators may benefit from resection of the parasympathetic nerve supply to the tracheobronchial tree. There may also be some advantage in removing the pathway from the stretch receptors. Denervation procedures are, however, rare in this country.

Removal of air cysts.

Occasionally a patient's disability may, in large measure, be due to air cysts or bullae. These may be entirely closed or in communication with the bronchus—the opening often being valvular and resulting in progressive distension. Improvement in function of the remaining lung may be obtained by obliteration or resection of the cyst (d'Abreu, 1953; Bromley, 1958).

Spontaneous pneumothorax.

Although this condition may occur in patients with no obvious pulmonary disease, it is frequently associated with either bullous or generalized emphysema (Brock, 1948). The recurrent condition may be treated by chemical pleurodesis, but some prefer to seal the leak at thoracotomy (Brewer et al., 1950). Anaesthesia presents no problems beyond those of thoracotomy in emphysematous patients.

ARTIFICIAL VENTILATION FOR CARBON DIOXIDE NARCOSIS

A small number of patients with severe emphysema pass into carbon dioxide narcosis which may be resistant to chemical stimulation. A tracheostomy alone may be sufficient to restore adequate alveolar ventilation but occasionally it is necessary to resort to artificial ventilation. A number of centres have used the technique and have managed to reduce the arterial carbon dioxide tension below narcotic levels. Many anaesthetists have now built up considerable experience in the long-term ventilation of patients in respiratory units, and their help may be sought in the treatment of carbon dioxide narcosis.

The principles of treatment have been outlined by Dornhorst (1958) in this symposium and it will be apparent that prolonged ventilation of unconscious emphysematous patients should not be lightly undertaken. To the problems of long-term artificial ventilation are added those of emphysema and specialized knowledge of each is required.

SUMMARY

Emphysema presents such a widespread disturbance of pulmonary function that anaesthesia may be complicated by a number of different factors. A knowledge of the disordered function due to the disease is essential to an understanding of the problems which confront the anaesthetist.

Associated bronchitis causes the tracheobronchial tree to be hypersensitive and anaesthesia may be complicated by coughing, breath holding or bronchospasm. Postoperative exacerbation of infection is a frequent occurrence and may have serious consequences.

Induction by inhalational anaesthesia is complicated by the delayed uptake of gases due to defective mixing. Respiration in emphysematous patients is particularly sensitive to depressant drugs and, in addition, they have a diminished

ventilatory response to a raised arterial carbon dioxide tension. Furthermore, reliance of these patients on the "anoxic drive" reduces the alveolar ventilation when the inspired oxygen concentration is raised unduly. These factors may precipitate a vicious circle of carbon dioxide retention leading to narcosis. After a long period of artificial ventilation, there may be some difficulty in restoring the blood gas tensions to levels which are compatible with spontaneous respiration.

Expiratory obstruction may complicate artificial ventilation and lead to hyperinflation with both respiratory and circulatory embarrassment. Cautious use of a reduced airway pressure during expiration may be of value.

Neither spontaneous respiration nor artificial ventilation is free from difficulties and many prefer to use local or regional analgesia when such techniques are practicable.

After thoracotomy there is danger of postoperative hypoventilation, particularly if much functioning lung has been removed. Artificial ventilation may be the only effective treatment.

Mention is made of certain operations to improve function in emphysematous patients and attention is drawn to the possible role of the anaesthetist in the treatment of carbon dioxide narcosis by artificial ventilation.

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THE EVOLUTION OF ANAESTHESIA

BY

M. H. ARMSTRONG DAVISON

Department of Anaesthetics, Royal Victoria Infirmary, Newcastle upon Tyne

(*Continued from Vol. 29, page 583*)

THE history of anaesthesia is a large subject; paradoxically, it is also true that it does not exist at all. Anaesthesia is merely a branch of medicine, and its history can only be understood by examining the whole subject. Equally, medicine is a branch of science, while science is but one facet of human activity; it follows, therefore, that the history of anaesthesia can only be interpreted correctly by viewing it in the perspective of other human activities, medical, scientific and social; inventions, discoveries, wars, religious beliefs, and all the manifestations of art and culture.

G. Modern Period (since 1846).

It is no part of our duty to give here a complete account of the history of the world during the past century, but it is necessary to draw attention to certain trends in human activity which have a bearing on our subject. At the time of the discovery of anaesthesia, there was a galaxy of great men in the world of science and art: the names of Wordsworth, Heine, Carlyle, Macaulay, Victor Hugo, Mendelssohn, Chopin, Darwin, Thackeray, Dickens, Wagner, Emerson, Longfellow, Browning and Tennyson give lustre to the age; but it was not only in the haut monde of culture that developments were afoot. The year 1848 saw revolutions in almost every European country, and even in Britain, the Chartist riots caused disturbance and dismay. All this was the logical sequence to the idea of democracy, first enunciated in the modern sense by John Knox in 1563, and reaching its goal in universal franchise, which, for better or for worse, was only to be obtained by long and bitter struggles.

Meanwhile, the great manufacturing developments were leading to increased prosperity and to a huge increase in the population of the industrialized countries, and with this combination of population and prosperity came the itch for power. Thus were born the great wars of the last eighty years, and from them also the present political instability. The growth of democracy within states is now being paralleled by a similar attitude of the countries themselves: the expression of "nationalism", often exploited to the disadvantage of the country concerned, is now a commonplace, and, in this sense, the two World Wars may be regarded as the counterparts, at a different political level, of the revolts of 1848 and later. With complete "democracy" of nations has come "political instability" on a world scale, and in such fashion as to make one doubtful of the future. Yet the outlook is not all black: the barbarous peoples of the early 18th century developed humanity with industrial revolution, and if a similar change occurs with the "democratization" of nations, as distinct from their individuals, then the future is bright indeed.

The developments of science in the last hundred years have been so obvious and so dramatic as to need no emphasis here. What is important, however, is the way in which medicine has learnt to make use of the most recent discoveries and inventions in other branches of science, and herein lies the main difference between the "Modern" period and the "Pre-Anaesthetic" age, when co-operation between medicine and science was negligible. The close association of all the branches of science is due to the great increase in means for the propagation of knowledge: the foundation of universities and schools of technology, the multiplication of learned societies and the publication of scientific journals.

The progress of medicine since the discovery of anaesthesia has been equally dramatic with that of the other sciences. At that date, there were only two specific curative drugs known: quinine for malaria, and ipecacuanha for amoe-

biasis; all other drugs were for symptomatic treatment only. Immunization, save for smallpox, was unknown; the germ-theory of disease was a forgotten philosophical concept; and antiseptics were not yet invented. The first great strides had, however, been taken in public health, and the study of statistics was beginning, but both these subjects had yet little influence. Medicine in 1846 was in the doldrums. The discovery of anaesthesia was a beacon-light which showed that further discoveries and inventions were possible, and that medicine was capable of advancing. Unfortunately, in the absence of a knowledge of the cause of infection, the discovery of anaesthesia led to a great increase in the amount of surgical interference with a correspondingly large mortality: in the years 1864–1866, Lister at Glasgow performed 35 amputations with a mortality of 16 (46 per cent), and these figures were better than most; in some hospitals the mortality from this operation was well over 60 per cent. In 1867, Lister introduced his antiseptic technique; in the years 1867–1870, he performed 40 amputations, with only 6 deaths (15 per cent). Antisepsis was not quickly adopted, and had many opponents who were gradually overwhelmed: from then onwards, surgical development was rapid, and the great era of the surgeon dawned. From 1880 to 1930, the surgeon was the hero of the medical world, but the developments in medicine in the last fifty years have lowered, by comparison, his prestige. Furthermore, the recent advances in anaesthesia and resuscitation have introduced a new type of surgery, meticulous and time-consuming, which lacks the dramatic brilliance of the earlier age, while the introduction of the National Health Service in Britain has also tended to level out the status of the specialties.

The first half-century of anaesthesia was largely occupied by the argument on the relative merits of chloroform and ether. It is surprising how few and how slow were the improvements before 1900, in spite of the immense impetus which was given to the subject by John Snow. It would seem as if his great book *On Chloroform and Other Anaesthetics* (1858) was either not read or read with a closed intelligence.

Fifteen years before the end of the 19th century, local analgesia was discovered, but it was not until the beginning of the 20th century that it began to take its rightful place, a place from which it has declined somewhat with the development of safer methods of general anaesthesia in the last twelve years, in spite of the discovery of better agents, such as lignocaine.

The first quarter of the present century saw the gradual displacement of chloroform and the virtual supremacy of nitrous oxide used in conjunction with ether, but this advance has already given way to relaxant and other intravenous techniques, and the use of hypothermia and extracorporeal circulation has widened still further our horizons. It is fair to say that these more recent developments owe much to what is, perhaps, the most important advance in technique since the introduction of anaesthesia: namely endotracheal inhalation, developed by Rowbotham and Magill in 1917–1920. The present combination of methods has made it possible for the surgeon to operate deliberately and definitively in every cavity of the body, and, so far from the prediction being correct, that the antibiotics would lead to the abolition of surgical intervention, the prospects for surgery are wider than they have ever been.

Against this background is to be set the introduction of the new drug, halothane. While it is not disputed that this drug may have some uses, it does not fit into the present trend of anaesthetic development, which is to produce narcosis, relaxation, and other desired phenomena, by separate drugs each with a specific action, rather than to return to the major use of agents with multiple effects. It therefore seems certain that, unless there be a great change in the line of evolution, it and similar drugs will play little part in the future of anaesthesia.

In retrospect, we can regard the last hundred years as being the age of the specialist, and, with the increase in scientific and medical knowledge, this specialism will increase. Thanks, however, to the means of propagating knowledge, each one, although he restrict his field more and more, nevertheless is better acquainted with other fields of work than has ever been the case in the past. It will therefore be seen that specialism is not merely a case of knowing more and more about less and less, but also of knowing more and more about everything. Fortunately, the human brain, unlike the electronic computing machine, has no

upward limit to its capacity, and herein lies the challenge of the future.

The following chronology is not intended to be inclusive: it is merely meant as a series of signposts to the development of medicine over this period; in subsequent articles the development of anaesthesia will be dealt with in detail.

1846. October 16. Morton demonstrates ether anaesthesia at the Massachusetts General Hospital.

1846. November 9. Bigelow reads a paper on etherization at the Boston Society of Medical Improvement. An account of this lecture was forwarded to Dr. Boott of Gower Street, London, some three weeks later.

1846. November 12. Patent delivered to Morton and Jackson.

1846. December 19. The first use of ether outside the United States of America. Dr. Boott wrote: ". . . a firmly fixed molar tooth was extracted in my study from Miss Londsdale by Mr. Robinson . . . without the least sense of pain . . . the whole process of inhalation, extracting and waking was over in three minutes." Hooper's apparatus was used.

1846. December 21. Liston, at University College Hospital, employs ether for (1) amputation of the leg and (2) avulsion of a toe-nail. Squire's apparatus was used.

1847. January 12. At a meeting of the Académie de Médecine in Paris, Malgaigne described 5 anaesthetics which he had conducted personally.

1847. January 19. James Young Simpson administers ether for the first time in midwifery.

1847. Semmelweiss (Vienna) introduces the use of an antiseptic (chloride of lime) for washing the hands before examining obstetric patients.

1847. Foundation of the American Medical Association.

1847. November 4(?). First use of chloroform by Simpson.

1848. January 24. Death of Horace Wells by his own hand.

1848. January 28. The first death under chloroform (Hannah Greener).

1848. Revolutionary movements in most European countries.

1849. John Snow, "On the Pathology and Mode of Communication of the Cholera." This paper in the *London Medical Gazette* demonstrated the waterborne nature of the disease. It was a triumph of deduction and is a milestone in the history of epidemiology.

1850. Von Helmholtz (1821–1894) invents an ophthalmoscope. Three years previously he had read his epoch-making paper "On the Conservation of Energy".

1850. William Detmold (New York) opens an abscess of the brain.

1851. The Great Exhibition in Hyde Park, London, was the first great demonstration of the progress of technology.

1852. Sir Richard Owen, while dissecting a rhinocerus, discovers the parathyroid glands.

1852. Louis Napoleon becomes Emperor of the French.

1853. Charles Gabriel Pravaz (1791–1853), inventor of the galvano-cautery, describes a glass syringe with tapered nozzle. This syringe was intended to be used with a special trocar for injecting ferric chloride into anurysms, and thus to heal them by coagulation.

1853. Alexander Wood (1817–1884) of Edinburgh invents the hypodermic needle and adapts Pravaz's syringe for use with it.

1853. At the birth of Prince Leopold, John Snow administers chloroform intermittently (in the manner later known as à la reine) to Queen Victoria. This event went a long way towards overcoming opposition on religious and moral grounds to the use of anaesthetics in midwifery.

1854. The Crimea. Florence Nightingale (1820–1910), with thirty-eight nurses, took charge of the hospital at Scutari, where conditions were indescribably bad. Miss Nightingale had studied nursing at various places on the Continent and had become superintendent at the Hospital for Invalid Gentlewomen in London. She became a national heroine, and subsequently founded a school of nursing at St. Thomas's Hospital: her efforts led to a revolution in nursing and to the opening of this career to women of good class and education.

1854. In the well-known Broad Street Pump episode, John Snow demonstrates the waterborne character of cholera. A public house close to the site of the pump (now Broadwick Street) has recently been named the "John Snow" in memory of this event. John Snow was a teetotaller.

1855. Manuel Garcia, a Spaniard and teacher of singing in London, describes the laryngoscope.

1855. Gaedicke extracts an alkaloid, erythroxyline, from the leaves of the coca plant.

1855. Bessemer's steel process invented.

1857. The Indian Mutiny.

1857. John Snow again administers chloroform to Queen Victoria at the birth of Princess Beatrice.

1857. Claude Bernard (1813–1878) publishes his *Leçons sur les Effets des Substances Toxiques*, in which he demonstrated that curare acted at the myoneural junction. He had previously published papers on curare in 1850. Bernard made many important discoveries, of which the most important are the glycogenetic function of the liver, the vaso-motor system (out of which grew his theory of maintenance of the milieu intérieur) and the digestive action of the pancreatic juice.

1858. The laying of the Atlantic cable.

1858. The death of John Snow at the moment of completing his book *On Chloroform and Other Anaesthetics*, which was seen through the press by his friend, (Sir) Benjamin W. Richardson.

1858. Passage of the Medical Act which established the General Medical Council in Great Britain.

1859. Charles Darwin (1809–1882) publishes his *On the origin of the Species*. His *Descent of Man* followed in 1871.

1859. Niemann isolates cocaine (originally, cocaïne) from the leaves of erythroxylon coca.
1860. China and Japan opened to European intercourse and trade.
1860. Joseph Wilson Swan of Newcastle makes the first carbon filament electric light.
1860. Ignaz Philipp Semmelweiss (1818–1865) published his *Etiology, Concept and Prophylaxis of Puerperal Fever* at Budapest. His idea of contamination was hotly disputed, although, under his antiseptic routine, the mortality had fallen in his clinic from more than 12 per cent to less than 1 per cent.
1861. Cavour and Garibaldi free Italy from Austrian domination and unite the country as a kingdom.
1861. Paul Broca (1824–1881) at Paris localizes the centre for speech in the third left frontal convolution of the brain.
1862. Joseph Clover describes an apparatus for administering chloroform in known percentage. The apparatus was identical with one described by John Snow in the *Lancet* in 1849.
1863. Hermann von Helmholtz (1821–1894) publishes his *Die Lehre von den Tonempfindungen*, the classic work on the physiology of sound.
1863. Louis Pasteur (1822–1895) demonstrates that fermentation is caused by microscopic organisms. It was this work which stimulated Lister, who recognized the resemblance between fermentation and putrefaction, to adopt his antiseptic method.
1864. The Royal Medical and Chirurgical Society's Chloroform Committee's report emphasizes the depressant action of chloroform on the heart, and recommends the use of mixtures of chloroform and ether.
1865. End of the Civil War in the United States of America, quickly followed by the assassination of Abraham Lincoln. The war had lasted just over four years. Crawford W. Long, who had used ether anaesthesia in 1842, served as an anaesthetist with the Confederate forces, and W. T. G. Morton served in a similar capacity with the Federal troops.
1865. Jean Antoine Villemin (1827–1892) shows that tuberculosis is infective and that the disease may be propagated by material from a granuloma: in other words, he anticipated Koch's "postulates" by 17 years.
1866. The Battle of Sadowa leads to the formation of the North German Confederation under Prussia.
1866. James Young Simpson created a Baronet.
1867. The Second Reform Act confers household and lodger franchise in boroughs.
1867. Bobbs of Indiana drains the gall-bladder.
1867. Joseph Lister (1827–1912), Professor of Surgery at Glasgow, publishes an article "On a New Method of Treating Compound Fracture, Abscess, etc.' in which he described the antiseptic method and attributed infection and putrefaction to airborne microbes.
1868. Death of William T. G. Morton from apoplexy in New York.
1868. Greene in the United States of America recommends the use of a pre-operative injection of morphine.
1868. George Barth in England popularizes the use of cylinders for the storage of nitrous oxide under pressure.
1869. Gustav Simon performs the first nephrectomy.
1869. Friedrich Trendelenburg (1844–1924). designs a method of endotracheal administration of anaesthetics through a tracheostomy.
1869. Suez Canal opened for traffic.
1870–1871. The Franco-Prussian War, followed by the Proclamation, at Versailles, of the foundation of the German Empire.
1872. P. C. Oré of Lyons uses intravenous chloral hydrate as an anaesthetic.
1873. Charles T. Jackson, claimant of the discovery of anaesthesia, becomes insane.
1873. Sir William Gull (1816–1890) describes myxoedema.
1875. Leonhard Landois discovers that animal serum will haemolyze human blood.
1876. Edoardo Porro of Pavia performs a successful Caesarean section with hysterectomy.
1876. Johns Hopkins University founded.
1876. Robert Koch (1843–1910) isolates the anthrax bacillus.
1876. Bell invents the telephone.
1877. Marc Nitze (1848–1906) invents the cystoscope.
1878. The Afghan War.
1879. The Zulu War.
1880. Death of Charles T. Jackson.
1880. Various workers advocate the pre-anaesthetic use of atropine.
1880. Klikovitch of St. Petersburg advocates nitrous oxide in midwifery.
1880. Sir William Macewen describes peroral endotracheal intubation with a brass tube to facilitate the removal of a large goitre.
1880. Advances in bacteriology include the isolation of staphylococci and streptococci (Pasteur) and of the typhoid bacillus (Eberth).
1880. (Sir) Joseph Swan at Newcastle upon Tyne gives the first large scale demonstration of electric lighting. Lord Armstrong's home, Cragside, at Rothbury, Northumberland, the first house to be lit by electric light, is built. Edison, who had worked independently, also developed an incandescent carbon-filament lamp, at about this time.
1881. Christian Albert Theodor Billroth (1829–1894) of Vienna performs the first gastrectomy.
1881. Anton Wölfler (1850–1917) performs the first gastro-enterostomy.
1881. Carlos Findlay of Cuba states that yellow fever is carried by the Culex (Aedes aegypti) mosquito.
1881. Pasteur demonstrates the prophylaxis of sheep against anthrax.
1881. Charles L. A. Laveran (1845–1922) discovers the parasite of malaria while serving with the French Army in Algeria.
1882. Koch discovers the tubercle bacillus.
1882. Carl Langenbuch (Berlin) performs the first cholecystectomy.

1882. The British occupy Egypt.
1882. September 15. Carl Koller, at the Ophthalmological Congress at Heidelberg, demonstrates the analgesic action of cocaine in the eye.
1885. James Leonard Corning of New York performs spinal aneasthesia (accidentally) on a dog.
1885. William Stewart Halsted (1852–1922), then at New York, performs the first regional anaesthetic by injection of cocaine into a nerve trunk.
1885. (Sir) Frederic Hewitt constructs the first practical apparatus for nitrous oxide and oxygen.
1885. Pasteur saves Joseph Meister, an Alsation boy of 9, who had been bitten by a rabid dog.
1886. Von Bergman introduces steam sterilization; this was the beginning of the aseptic era in surgery.
1887. T. G. Morton of Philadelphia, son of the discoverer of anaesthesia, performs the first appendicectomy for acute appendicitis.
1887. Taylor of Birmingham attempts to suture a perforated peptic ulcer.
1888–1889. Hyderabad Chloroform Commissions.
1889. Foundation of Johns Hopkins Hospital.
1889. Infectious diseases made notifiable in Britain.
1890. Halsted, now at Baltimore, introduces rubber gloves for the benefit of his theatre sister, who ultimately became his wife.
1891. Essex Wynter in England and Henrich Quincke (the discoverer of angioneurotic oedema) in Germany describe lumbar puncture.
1891. George Murray of Newcastle upon Tyne treats myxoedema with thyroid extract.
1892. Carl Ludwig Schleich demonstrates local infiltration with cocaine.
1892. Heusner performs the first successful suture of a perforated peptic ulcer.
1893. Foundation of the Johns Hopkins Medical School. The staff of the school was composed of many eminent men, chief among whom were Welch, Osler, Kelly and Halsted.
1893. Foundation of the Society of Anaesthetists of London.
1894. Gustav Kirstein invents a direct laryngoscope.
1894. Ethyl chloride first used (accidentally) as a general anaesthetic.
1895. Wireless telegraphy introduced by Marconi.
1895. Nobel prizes instituted.
1895. Wilhelm Conrad Röntgen (1845–1923) of Würzburg discovers X-rays.
1896. Widal and Siccard introduce the agglutination test for typhoid fever.
1896. Louis Rehn of Frankfurt performs the first operation on the heart, successfully suturing a stab wound and evacuating a haemopericardium.
1896. Riva-Rocci introduces the mercury sphygmomanometer.
1897. Joseph Lister elevated to the peerage with the title of Baron Lister of Lyme Regis. He was the first medical man to be raised to the English peerage.
1898. Gustav Killian of Freiburg performs bronchoscopy.
1898. Pierre and Marie Curie discover radium.
1898. August Bier (1861–1949) performs spinal anaesthesia on man.
1899. Korff introduces "twilight sleep" with morphine and hyoscine.
1900. Karl Landsteiner of Vienna discovers human blood groups.
1901. Sicard and Cathelin perform sacral epidural analgesia.
1902. Charles Richet (1850–1935) of Paris discovers the phenomenon of anaphylaxis.
1902. Ernest Henry Starling (1866-1927) of London discovers hormones.
1903. Emil Fischer (1852–1919) and von Mering synthesize barbitone.
1903. Einthoven invents the string galvanometer.
1904. Ferdinand Sauerbruch (1875–1951) introduces a pressure cabinet to facilitate surgery in the open thorax.
1904. Report of the Chloroform Committee of the British Medical Association which recommended the use of Vernon Harcourt's apparatus, which was designed to deliver not more than 2 per cent of chloroform vapour in air.
1905. Heinrich F. W. Braun (1862–1934) introduces procaine, which had been first prepared by Alfred Einhorn in 1899.
1905. Fritz Schaudinn (1871–1906) discovers the Spirochaeta pallida, later renamed Treponema pallidum.
1905. Nikolai Korotkoff (b. 1876) introduces the auscultatory method of measuring the blood pressure.
1907. Florence Nightingale becomes a member of the Order of Merit.
1907. Barthélemy and Dufour describe the endotracheal insufflation method of administering anaesthetics.
1908. Friedrich Trendelenburg (1844–1924) develops his operation of pulmonary embolectomy, but has no successful results.
1909. Meltzer and Auer use endotracheal insufflation on animals, and Elsberg uses it in man.
1910. Paul Ehrlich (1854–1915) and S. Hata (1873–1938) describe salvarsan ("606") in the therapy of syphilis. This was the first occasion on which chemists succeeded in producing a drug which had a predetermined action.
1911. A. Goodman Levy and T. Lewis publish their epoch-making paper, *Heart Irregularities Resulting from the Inhalation of low Percentages of Chloroform Vapour, and their Relationship to Ventricular Fibrillation*, which explained the mechanism of "primary cardiac failure" under chloroform. This work largely stultified the report of a British Medical Association Committee which appeared the same year.
1912. Hartwell and Hoguet stress the importance of restoring to the patient fluid lost by vomiting.
1912. Casimir Funk (b. 1884) demonstrates the cause of beri-beri; he proposed the term "vitamines" for certain nutritional elements: since the discovery of the chemical formulae of some of these showed them not to be amines, the name has been changed to "vitamins".

1912. Death of Lord Lister.
1912. Formation of National Health Insurance scheme in Britain.
1912. (Sir) Robert Kelly popularizes endotracheal insufflation anaesthesia in England.
1914. Théodore Tuffier (1857–1929) performs the first successful valvotomy for valvular disease of the heart. Doyen of Lyons had unsuccessfully attempted a similar operation in the previous year.
1915. Dennis Jackson describes an anaesthetic apparatus which employed rebreathing with absorption of carbon dioxide.
1915. Franz Torek of New York successfully performs oesophagectomy.
1917. H. E. G. Boyle's first anaesthetic apparatus, inspired by earlier American machines.
1920. E. S. Rowbotham describes endotracheal inhalation anaesthesia. In the following year, he and I. W. Magill reported on nearly 3,000 cases.
1923. Haden and Orr demonstrate the importance of restoring chloride lost by vomiting.
1924. R. M. Waters introduced a practical apparatus for the absorption of carbon dioxide from anaesthetic atmospheres.
1924. Kirschner performs the first successful pulmonary embolectomy.
1929. Fleming discovers the bacteriostatic effect of penicillin in vitro.
1929. Hans Berger of Jena introduces electroencephalography.
1930. R. M. Waters introduces cyclopropane anaesthesia.
1931. Nissen performs the first successful pneumonectomy. Gluck in 1881 had already demonstrated on animals the possibility of this operation; in 1895 Macewen had removed a necrotic lung piecemeal; and in 1911 Kümmell had attempted pneumonectomy unsuccessfully.
1932. Weese and Scharpff develop Evipan (hexobarbitone).
1932. Leake and Chen introduce di-vinyl ether.
1933. Wangensteen introduces the aspiration treatment of intestinal obstruction.
1934. J. S. Lundy introduces Pentothal (thiopentone).
1934. R. J. Minnitt introduces an apparatus, suitable for use by midwives, for administering an analgesic concentration of nitrous oxide and air.
1935. Gerhard Domagk introduces prontosil, the first of the "sulpha" group of antibiotics.
1935. Striker experiments with trichloroethylene as an anaesthetic.
1935. King elucidates the structural formula of d-tubocurarine.
1938. Devine describes the synchronous abdominal and perineal operation for excision of the rectum.
1938. Crafoord constructs the "spiropulsator", the first practical positive pressure respirator for use in anaesthesia.
1940. Wiener and Landsteiner discover the rhesus factor in human blood.
1941. C. Langton Hewer introduces trichloroethylene.
1942. The isolation of adreno-cortico-trophic hormone. Cortisone had been isolated in 1936.
1942. H. R. Griffith and G. E. Johnson describe the use of curare in anaesthesia.
1942. F. M. Allen reports on refrigeration anaesthesia for amputation.
1942. R. A. Hingson and W. B. Edwards introduce continuous caudal analgesia in obstetrics.
1943. Florey introduces penicillin.
1948. Introduction of the National Health Service in Britain.
1948. Formation of a Faculty of Anaesthetists in the Royal College of Surgeons of England.
1952. Laborit and Huguenard introduce "hibernation".
1952. Cookson, Neptune and Bailey describe hypothermia in man.
1957. Halothane, developed by Imperial Chemical Industries, introduced into anaesthetic practice.

(To be continued)

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THE JUNIOR ANAESTHETIST AT WORK

BY

R. M. A. McCLELLAND

Royal Air Force Hospital, Cosford

THE record of my experience as a junior anaesthetist* reflects something of postgraduate opportunity three years ago in this specialty; it may serve as a standard for comparison.

Since the work was performed at a teaching hospital in London from January 1 to June 30, 1954, and over the same period of 1955 in a peripheral hospital group, my experience and capabilities had grown by the time I began to work in the periphery.

The admission of patients was controlled in the teaching hospital; in the peripheral hospitals choice was lacking and hence there were more patients with chronic diseases here and more "emergency" operations were performed. The teaching hospital had some six hundred beds and the peripheral group had one thousand; these being divided amongst a small number of hospitals located within a three-mile radius from the centre of the city, which was a holiday resort and a port.

Four consultants, three registrars and two junior anaesthetists made up the anaesthetic staff of the teaching hospital, whereas eight consultants, one registrar and three juniors worked as a "pool" of anaesthetists in the peripheral group.

In the teaching hospital (which also had a dental centre) instruction by consultants and registrars was of a high standard. One's initial confidence to deal with anaesthetic problems was initiated here under ideal conditions. An anaesthetic problem new to junior anaesthetists could be tackled after previously watching a senior anaesthetist at work on similar problems, or by giving anaesthetics under direct supervision, otherwise one could work under indirect supervision in the certain knowledge that advice and aid were immediately available if required. There was a relative lack of easily available experienced anaesthetists in the peripheral group. This had the advantage that it allowed for the development of initiative, and no criticism of the administration of the anaesthetic departments is intended.

I have included in the following tables only those patients I anaesthetized without advice or aid from consultants or registrars, and this applies to both hospital groups.

CLASSIFICATION OF THE OPERATIONS

Opinions differ on what constitutes a major or a minor surgical operation. For this reason I have included the details of the classification which follows, and on it succeeding tables are based.

Operations at the Teaching Hospital.

Major operations.

Major operations at the teaching hospital included those for perforated peptic ulcer (3), foreign bodies in the oesophagus (3), burst abdomen (2), intestinal obstruction (2), perforated ectopic pregnancy (2), multiple abscesses with sinus formation (2), amputation of lower limbs (2), multiple compound fractures (2), orthopaedic conditions (5), and a miscellaneous group (20).

Minor operations.

Minor operations were for appendicitis (28), dilatation and curettage of the uterus (15), strabismus (9), superficial abscesses (9), dental procedures (7), varicose veins (7), hernia (5), cystoscopy (4), removal of tonsils and adenoids (3), suture of tendons (3), skin grafts (3), post-prostatectomy clot retention (2), orthopaedic conditions (32), and a miscellaneous group (28).

Operations at the Peripheral Hospitals.

Major operations.

Major operations at the peripheral hospitals included those for peptic ulcer requiring par-

* House officer grade at teaching hospital; senior house officer grade at the peripheral hospitals.

tial gastrectomy (23), uterine disease requiring hysterectomy (15), multiple compound limb fractures (14) prostatectomy (12), perforated peptic ulceration (10), mastectomy (10), intestinal obstruction (9), cholecystectomy (8), uterine prolapse (7), perforated ectopic pregnancy (6), submucous resection of the nasal septum (6), antrostomy (5), nephrectomy (4), fixation of fractured femur (4), hemicolectomy (3), intestinal volvulus (3), retinal detachment (3), mastoiditis (3), perforated diverticuli (2), intussusception (2), and a miscellaneous group (18).

Minor operations.

These included appendicectomy (76), uterine dilatation and curettage (57), cystoscopy (20), orthopaedic operations (19), removal of tonsils and adenoids (17), varicose veins (15), hernia (11), bronchoscopy (8), suture of tendons (8), ophthalmic operations for strabismus (7), dental operations (5), skin grafts (5), and a miscellaneous group (52).

OPERATIONS IN THE TEACHING AND PERIPHERAL HOSPITALS COMPARED

Table I shows that more anaesthetics were given by me in the peripheral hospital and the majority of these were minor operations. On the other hand I gave more anaesthetics for casualty and dental work at the teaching hospital. I encountered more than three times as many major operations in the peripheral hospitals.

Table II compares major operations according to their anatomical site in both types of hospital. Operations involving the upper abdomen in the peripheral hospital were five times as many as in the teaching hospital and almost half the total number in the peripheral hospitals; the second largest group in the peripheral hospitals were gynaecological operations.

The largest group of minor operations involved the lower abdomen and these occurred within the peripheral hospitals where there was also a preponderance of gynaecological operations. The

TABLE I

Proportions of in-patient and out-patient operations and their subdivisions.

	T	Per cent of total	P	Per cent of total		T	P
In-patient operations	229	43	494	80.5	Major	43	167
					Minor	155	300
					Obstet	31	27
Out-patient operations	305	57	119	19.5	Casualty	148	103
					Dental	157	16
Totals	534		613				

T = Teaching hospital. P = Peripheral hospital

TABLE II

Major and minor operations in teaching and peripheral hospitals.

Operations	Major		Minor	
	Teaching	Peripheral	Teaching	Peripheral
Lower abdomen	1	8	32	104
Upper abdomen	12	60	3	5
Gynaecological	7	28	17	57
Urological	2	16	6	24
Thoracic	—	—	—	8
Ear nose and throat...	5	14	3	17
Ophthalmic	2	4	9	11
Orthopaedic	11	20	35	27
Dental	—	1	7	5
Others	3	16	43	42
Totals	43	167	155	300

largest group of operations in the teaching hospital was orthopaedic. Bronchoscopy was included in the thoracic group in the peripheral hospitals where I also gained some experience in anaesthesia for patients with fractured jaws. The relatively larger number of minor orthopaedic operations in the teaching hospital was probably due to a selection of these procedures for a junior anaesthetist.

Table III compares the obstetrical operations. Under the heading "others" are included such procedures as the artificial rupture of the membranes. Only the peripheral hospitals provided opportunities for giving anaesthetics for Caesarean section. This may have been because I lacked experience at the beginning. There were equal chances for giving anaesthetics for forceps delivery, but in the teaching hospital I gave more anaesthetics for the removal of retained placentae.

TABLE III
Comparison of obstetrical operations.

Obstetrical operations	Teaching	Peripheral
Caesarean section ...	—	12
Forceps	14	13
Retained placenta	10	1
Others	7	1
Totals	31	27

Operations performed upon Patients with a Vomiting Hazard.

Table IV classifies operations performed in patients who were considered as likely to have a vomiting hazard. This group comprises "emergency" operations, casualty and the majority of dental operations, although some warning about the danger of having a full stomach before anaesthesia was probably given to most of the dental and casualty patients.

TABLE IV
Operations on relatively unprepared patients.

Group	Teaching	Peripheral
Major	27	66
Minor	60	130
Obstetric	24	26
Casualty	148	103
Dental	157	16
Totals	416	341

A greater number of operations on the relatively "unprepared" patients was performed at the teaching hospital, but if the casualty and dental groups are excluded the numbers in the periphery are double those at the teaching hospital. Table V shows the different kinds of operation encountered at each hospital in relatively "unprepared" patients. The largest single group of these were lower abdominal operations which occurred at the peripheral hospitals. The largest group of major operations in these patients in the peripheral hospital were upper abdominal and orthopaedic. Lower abdominal and gynaecological operations comprised the largest group of minor operations. Major upper abdominal operations included those for intestinal obstruction and perforated viscera. Motor-cycle accidents accounted for most of the increase in major orthopaedic operations in the peripheral hospitals.

Appendicectomy was the most frequent operation in the lower abdominal group and

TABLE V
Major and minor operations on relatively unprepared patients.

	Major		Minor	
	Teaching	Peripheral	Teaching	Peripheral
Lower abdomen	1	2	23	82
Upper abdomen	12	29	3	5
Ear, nose and throat	4	3	—	—
Thoracic	—	—	—	1
Ophthalmic	1	1	—	—
Gynaecological	2	6	9	27
Urological	1	1	2	1
Orthopaedic	5	16	11	6
Dental	—	1	—	—
Others	1	7	12	8
Totals	27	66	60	130

TABLE VI
Grade of fitness of patients for various groups of operations.

Grade	Major		Minor		Obstetrical	
	Teaching	Peripheral	Teaching	Peripheral	Teaching	Peripheral
1	26	67	99	191	22	15
2	13	53	53	78	8	11
3	3	41	3	29	1	1
4	1	6	—	2	—	—
Totals	43	167	155	300	31	27

miscarriages, whether intentionally induced or natural, resulted in practically all the minor gynaecological operations. These operations were rarely performed at the teaching hospital, and the rate for this operation at the periphery was more than one per day.

CONDITION OF THE PATIENTS

Operative risk cannot be gauged in precise terms and the four grades detailed later are intended to be no more than a rough clinical guide. The grades were judged as follows:

Grade 1. No abnormalities except that for which the operation was performed; e.g., acute appendicitis in a fit subject.

Grade 2. Presence of a pathological lesion not connected with condition for which the operation is to be performed; e.g., mitral stenosis without heart failure in a patient requiring a partial gastrectomy.

Grade 3. Presence of a complicating factor which dictated some modification in the anaesthetic procedure, e.g., resuscitation of a patient with a limb fracture requiring operation.

Grade 4. A desperately ill patient having no hope of survival without operation and with little chance of recovery, e.g., a patient with a perforated viscus which burst three days before, arriving for operation after a long journey to hospital.

Table VI shows the grade of fitness of patients for various groups of operations. On the whole the more serious risks were incurred in the peripheral group of hospitals. This may, on occasion, have been related to the long journeys some of the patients had to undertake before reaching hospital (several patients had to travel seventy miles); or it may have been because, as my experience had grown, I was given greater responsibilities.

Table VII shows that more of the older patients had operations in the peripheral group.

TABLE VII
Ages of patients.

Age	0–15	15–50	50–70	70–90
Operations				
TEACHING HOSPITAL				
Major	9	23	9	2
Minor	34	85	31	5
Total	43	108	40	7
PERIPHERAL GROUP				
Major	10	55	70	32
Minor	60	163	55	22
Total	70	218	125	54

Table VIII shows the number of patients to whom I had to administer anaesthesia who were relatively unprepared for operation. There were slightly more than double the total numbers at the peripheral hospitals for each age group, and there was in each group about double the number of unprepared patients with exceptions in the 0–5, 70–80, and 80–90 year groups.

TABLE VIII
Age related to patients relatively unprepared for operation.

Age	Major and minor operations	
	Teaching	Peripheral
0–5	6	3
5–10	7	14
10–15	5	23
15–50	49	100
50–60	8	21
60–70	9	15
70–80	2	15
80–90	1	5
Total	87	196

Table IX shows the grades of risk in each age group in the teaching as compared with the peripheral hospitals. Up to 10 years the risks appear about the same; between 15 and 50 years more of the third grade were encountered in the peripheral hospital than would have been expected with double the total number being in this group of hospitals. Between 50 and 90 years the risks appear much greater in the peripheral hospitals.

TABLE IX
Age related to risk.

Age	Risk	Teaching	Peripheral
0–5	1	15	13
	2	—	3
5–10	1	11	15
	2	3	2
	3	—	1
	4	1	—
10–15	1	13	30
	2	—	4
	3	—	2
15–50	1	74	141
	2	28	56
	3	6	20
	4	—	1
50–60	1	11	40
	2	13	20
	3	—	12
	4	—	1
60–70	1	1	12
	2	15	23
	3	—	14
	4	—	3
70–80	1	—	6
	2	6	20
	3	—	13
	4	—	3
80–90	1	—	1
	2	1	3
	3	—	8
Totals	1	125	258
	2	66	131
	3	6	70
	4	1	8

THE ANAESTHETICS AND THE TECHNIQUES OF ADMINISTRATION

I was taught the fundamentals about anaesthetics and their techniques of administration at the teaching hospital, but certain new methods were introduced and evolved at the peripheral hospitals.

Local anaesthesia played only a small part; two techniques were used, namely brachial plexus block and low spinal anaesthesia (heavy nupercaine). The former I used for casualty patients at both hospitals, and the latter only at the peripheral hospitals for major and minor general surgery.

General anaesthesia was given by a variety of techniques, and those learnt at the teaching hospital included:

(1) Open mask ether.

(2) Nitrous oxide, oxygen, trichloroethylene, carbon dioxide, ether sequence for all paediatric patients.

(3) The triad of narcosis, analgesia and relaxation, using thiopentone for induction, and nitrous oxide oxygen aided by ether, trichloroethylene or pethidine as maintenance; relaxant drugs of both the depolarizing and nondepolarizing types were used freely.

(4) If controlled respiration was considered desirable a high flow rate of gases in a to-and-fro circuit with a deliberate leakage was employed.

I found these methods proved satisfactory at the peripheral hospitals, but in addition the following methods and techniques were adopted:

(1) Open mask ethyl chloride or vinyl ether anaesthetic mixture as induction, prior to open mask ether.

(2) Induction with cyclopropane for paediatric patients.

(3) Minimal thiopentone followed by a cyclopropane and oxygen mixture—for dilatation and curettage of the uterus—administered through a circle carbon dioxide absorption circuit.

(4) For the grade 4 risk patients at the peripheral hospitals, I limited premedication to atropine, induced and intubated using volatile agents alone, and maintained anaesthesia with nitrous oxide and oxygen on a to-and-fro circuit, supplementing when necessary with pethidine and diluted tubocurarine, 1 mg/ml; this proved to be a satisfactory method for dealing with the exceptionally poor risk type of patient.

For a group comprising obstetric, casualty and dental patients, identical methods and techniques were employed at both teaching and peripheral hospitals. These were a nitrous oxide, oxygen, trichloroethylene, carbon dioxide, ether sequence for all obstetrical operations, including Caesarean sections, and nitrous oxide oxygen and trichloroethylene for both casualty and dental patients. The only use I found for thiopentone within this

group was for reduction of dislocations, and in prepared orthopaedic out-patients for manipulative procedures.

Decisions not to administer anaesthesia. I never refused to give an anaesthetic whilst serving in the teaching hospital, but I declined to do so on four occasions whilst working in the peripheral hospitals. On one of these, the patient had Ludwig's angina, but fortunately a consultant anaesthetist was able to undertake the administration of anaesthesia. On the other three occasions I was the only anaesthetist available and it seemed that the induction of anaesthesia was not justified. Within four hours of making this decision each of the patients had died.

Mortality. There were no deaths in the operating theatres at any of the hospitals, but two patients died within 24 hours of operation in the periphery. One of these patients was classified as a grade 3 risk and the other as grade 4. One stillbirth occurred in each hospital, but both the mothers had an advanced degree of toxaemia of pregnancy.

CONCLUSIONS

(1) The London teaching hospital and the peripheral hospitals offer a different group of problems for the anaesthetist, and this should be allowed for in postgraduate training schemes.
(2) Trainees should have the benefit of both kinds of experience.
(3) Practical instruction should be begun at the teaching hospital or at a hospital where the anaesthetic staff is more than adequate for the service requirements and can routinely provide practical postgraduate teaching.

ACKNOWLEDGMENTS

I am grateful to Drs. V. F. Hall and T. T. P. Murphy for kindly allowing me to publish figures relating to the work I did in their departments, and also to all those who have given me encouragement and help, at a time when I was developing the skills peculiar to this subject.

CORRESPONDENCE

ANAESTHESIA FOR ADENOTONSILLECTOMY

Sir,—I would like to enlarge on some points raised in Dr. Doughty's article on "Anaesthesia for Adenotonsillectomy" (*Brit. J. Anaesth.* (1957), **29**, 407), the importance of which you so rightly underline in your Editorial.

Many anaesthetists, of which I am one, feel that intubation, however carefully performed, should not be undertaken lightly, especially in small children. The actual placing of the tube can be done without inflicting any trauma on the delicate laryngeal and tracheal mucosa, but subsequent movement is bound to occur with its traumatizing effect. Especially is this so during the act of coughing which is inevitable in the light planes of anaesthesia recommended. Another fact so easily forgotten is that the internal diameter of any endotracheal tube is much less than that of the normal air passages, and minor degrees of compression are so easily unnoticed with the tube hidden under a tongue plate and in a darkened theatre. I would admit that with some surgeons the passage of a tube may be the lesser of many evils, but with many surgeons there is never the danger of a pharynx full of blood and the most careful dissection of the tonsils and removal of the adenoids does not take more than 10 minutes. In such cases the child does not have to be "saturated" with ether. Dr. Doughty's picture of a "pale, waxy child for at least 24 hours postoperatively" is much more suggestive of blood loss as the cause. I feel sure that many anaesthetists would agree that ether is a better and safer supplement than the at present imperfectly understood halothane which he recommends.

I am particularly interested in his type of premedication, and would strongly support his condemnation of the barbiturates for this purpose, a point which you also emphasize in your Editorial. I tried papaveretum and scopolamine some time ago, but was soon asked to give it up by the Ward Sister. This was due to an increase in the postoperative sickness; and, more important, I had a number of cases of respiratory depression in spite of most careful control of dosage. I believe others have given it up for the same reason. In my search for a safe drug I tried methylpentynol (Gusterson, 1955). I was therefore interested to read Dr. Kelsall's letter (*Brit. J. Anaesth.* (1957), **29**, 527).

In my original work I found that children's chief objection to hospital was of "needle pricks". I therefore tried dissolving the atropine in the elixir of methylpentynol. But this made a very nauseous mixture and the children were not dry enough for comfort. I next dissolved hyoscine in the elixir of methylpentynol, and this proved so satisfactory that it has become our routine practice. We use the following dosage scheme:

Age (years)	Elixir methylpentynol (drachms)	(ml)	Hyoscine (grains)	(mg)
2	2	7	1/150	0.43
3	2	7	1/150	0.43
4	2–3	7–10	1/100	0.65
5–7	3	10	1/100	0.65
8	4	14	1/100	0.65

The child arrives in the anaesthetic room in a placid state, and the fact that it has had no preoperative injection makes the venepuncture for the thiopentone induction a very easy and unhurried procedure. We observed some cases recently to assess their reaction to this venepuncture, using a classification similar to that of Dr. Doughty. The table shows the results which are much the same as those obtained by Dr. Doughty with his premedication.

Reactions of Children to Venepuncture.

Reaction	Premedication: Atropine only	Premedication: Methylpentynol/hyoscine
Smiled	5	12
Impassive	18	26
Winced	16	2
Cried	11	10
Total	50	50

There is no respiratory depression with the methylpentynol/hyoscine mixture, and the margin of safety is such that accurate weighing of the child is unnecessary. Also, provided that at least one hour elapses after the mixture is drunk, the actual timing of the operation is not so important as with morphia. These facts are of value when of necessity routine lists have to be worked.

We did also undertake a follow-up of cases going through the tonsil wards of Worthing Hospital. I know all the problems connected with the interpretation of such follow-ups, and will therefore content myself with reporting that no child receiving methylpentynol/hyoscine premedication expressed any fear of return to hospital or other emotional upset. Of those receiving atropine only as premedication over 10 per cent were pronounced by their mothers as having been upset by their hospital experience.

F. R. GUSTERSON
Worthing

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A NEW ANALEPTIC: PRELIMINARY COMMUNICATION

Sir,—In the armamentarium of the anaesthetist it is desirable to have respiratory and cardiovascular stimulants which will also reverse the narcotic and hypnotic effects of the opiates and barbiturates.

While it is generally safe to allow a patient to "sleep off" the effects of clinical doses of thiopentone (with or without supplementary anaesthesia), there are occasions when it is highly desirable to produce a rapid reversal to full consciousness.

Nikethamide, bemegride and picrotoxin have been used for this purpose, but have not proved by any means wholly satisfactory. Vanillic acid diethylamide (Vandid) has been used on nearly 40 occasions and has appeared to fulfil the requirements more adequately. In 5 patients there have been mild convulsions lasting less than 30 seconds, but in one it lasted for 1¼ minutes. In no case was there any untoward effect. These cases were all near the beginning of the series when the dose used was probably too large and given too quickly. Convulsions have not occurred in the last 25 consecutive cases.

The cases in which Vandid has been used include bronchoscopies, oesophagoscopies, manipulations of spine, shoulder and elbow, E.U.A.s and after the introduction of catheters for retrograde pyelography. Times of waking sufficiently to answer questions and obey orders such as "Hold your breath" have been noted carefully in over 30 patients; these have been correlated against the dose of thiopentone, the use of other agents, the build of the patient, etc. A very strong impression is that these times are considerably less than with other drugs for like cases. A more comprehensive control series is, therefore, being undertaken, and it is hoped to publish these results in due course.

Vandid has also been used as a respiratory stimulant when the tidal volume, as shown with a Rubens valve, after a minor operation appeared to be quite inadequate to permit of safe return to the ward. The results in all 3 patients were excellent.

In 1 patient with barbiturate poisoning Vandid was the only analeptic exhibited with, according to the medical registrar in charge, a dramatic recovery to full consciousness. Small increments of the drug were given over the next few hours to prevent a relapse into coma. It is interesting to note that in this patient there were no convulsions. We intend to make further trials with Vandid in treating barbiturate coma.

ERIC K. GARDNER
Barnet

LIFESAVING SIMPLICITY

Sir,—I should like to support Dr. Youngman (*Brit. J. Anaesth.* (1958), **30**, 48) in his plea for the elimination of an unnecessary and potentially dangerous bypass tap.

Dr. Youngman points the way to safety through the elimination of unessential complica-

tions. I suggest two further steps in the same direction:

(1) The elimination of the breathing bag tap on the Magill assembly. If the bag is not required, its mount can be unplugged and removed.

(2) The elimination of the soda lime control tap in the circle absorber. It requires only minor alteration of design (in most cases) to allow for the unplugging and removal of the soda lime canister and the visible reconnection of the circuit without it, on the rare occasions when this is needed. This was, in fact, the arrangement in a German circle absorber about 1950.

In recent years the technical experts have done much to protect us from the dangers of anaesthetic explosions, wrongly connected cylinders, and the introduction of trichloroethylene into closed circuits. But these are comparatively rare accidents that most of us have never seen. We must all have been alarmed, or at least annoyed, by a sudden respiratory obstruction due to the accidental turning off of the breathing bag by a passing nurse or onlooker, or a sweating brow because some unseen enthusiast has turned off the soda lime between administrations.

The pharmacology of anaesthesia necessarily becomes more complicated. In the design of our basic apparatus I appeal for lifesaving simplicity.

D. R. HUGHES
Hythe, Kent

BOOK REVIEW

The Respiratory Muscles and the Mechanics of Breathing. By E. J. Moran Campbell. Published by Lloyd-Luke. Pp. 131. Price 20s.

Anaesthetists should pay particular attention to the secondary title of this book for it is the chapters on the mechanics of breathing which will be of particular service to them. Chapters 9 to 16 provide a lucid and informative account of the organization of the breathing muscles and the mechanical basis of the function they perform. The earlier chapters deal separately with the various muscles implicated in normal and pathological forms of breathing, and contain a great deal of information which is otherwise difficult to trace in the literature. The book will repay careful reading and re-reading. Thereafter it is likely to remain a valuable reference volume for a considerable time.

E. A. Pask

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